A STUDY OF SOME FACTORS AFFECTING THE MAGNESIUM NUTRITION OF PLANTS

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I. INTRODUCTION.

Until recently, the importance of Mg as a plant nutrient has been neglected as a result of the emphasis on N, P, K, and Ca (lime). Compared with their requirements for these nutrients, particularly N and K, the demand of most crops for Mg is relatively small, and it had been assumed that soils contained enough Mg to meet these demands. However, the occurrence of Mg deficiency is becoming increasingly common in crop plants, due partly to greater removal of Mg from the soil associated with increased crop yields, and to progressive losses by leaching especially on light soils. Little compensation for these losses has been made by application of Mg fertilisers, except where magnesian limestone has been used, and although Mg is a common impurity in calciferous limestone, there is little Mg now being added to the soil incidentally as an impurity in other fertilisers, as increasing transport and labour costs have made it an economic necessity to use fertilisers of high chemical purity in a concentrated form.

Mg has various functions in the plant, and although the others are no less important, the most easily recognised is its participation as the central atom in the chlorophyll molecule. However, only about 10% of the Mg in green leaves is present in chlorophyll: the rest occurs either in solution in the cell sap or in combination with organic constituents of the plant. The actual form of the organic Mg compounds is not known.

The other functions of Mg in the plant are less well defined, but it plays a part in the activation of certain enzyme systems, including some of those concerned in the P and carbohydrate metabolism of the plant.

The/

The most obvious sign of an insufficient supply of Mg is the inadequate formation of chlorophyll, which results in chlorosis and mottling of the leaf, but these symptoms appear only when Mg shortage is acute. Lack of sufficient chlorophyll restricts photosynthesis and reduces crop growth, but it is not known to what extent yields are affected without visible deficiency symptoms being detectable. Deficiency symptoms are not always accompanied by a reduction in yield.

Although marked effects on crop yield caused by Mg fertilisation have been observed, often there is little or no effect, even when the plant Mg content is low. Other fertilisers often have a greater influence than that of applied Mg on the Mg content and Mg uptake of plants.

Plant species differ in their ability to absorb Mg. The absorption of Mg by a particular plant species depends not only on the concentration of the Mg ion in the soil, but also on the concentration of other ions present. Mg is subject to a number of ion interactions which greatly affect its utilisation. Cations may be antagonistic and inhibit the absorption of Mg as a result of processes in the soil or in the plant, and anions may be synergetic and increase Mg absorption. Whether Mg absorption is increased or decreased by application of a particular fertiliser depends to a large extent on the relative effects on Mg absorption of all ions added. Ion antagonisms are particularly important for Mg, as the Mg ion diffuses slowly, and it is likely to suffer in competition for entry into the plant with more mobile cations such as K.

Present knowledge on how ion interactions affect Mg absorption by plants following application of fertilisers to the soil is far from complete. The position/

position is complicated, as many factors other than direct ion interactions are involved. This is obvious from reports of previous research in which a particular fertiliser does not always affect the absorption of Mg in the same manner. For example, many workers have reported that application of $(NH_4)_2SO_4$ to the soil decreased the Mg content of plants, while other workers have reported increased plant Mg content following $(NH_4)_2SO_4$ application. Investigations into the effect of lime on Mg absorption have produced similarly conflicting results.

In this investigation a series of pot and field experiments was conducted, in seasons 1961 - 1963, to study the effects and interactions of soil applications of NO_3- and NH_4-N, Mg, K and lime on the growth and Mg uptake of oats and barley at various stages of growth.

II. REVIEW OF LITERATURE.

As the main object of the present work was to study the influence of K, Ca, H, N, and Mg on Mg uptake by plants and the interactions among these nutrients, the literature was reviewed under the following headings —

1. Mg and K.
2. Mg and Ca.
3. Mg and H.
4. Mg and N.

A more extensive review of the literature (up to 1955), on the role of Mg in plant nutrition, has been published by Jacob (60).

1. Mg and K.

The K ion is very mobile and luxury uptake can occur at the expense of other cations when the level of soil K available to plants is high. In a study of the mutual replacement of cations added as carbonates to a soil growing Italian ryegrass, van Itallie (57) found that uptake and replacement occurred in the order K > Na > Mg > Ca. York et al. (163) showed that K absorption was not much influenced by other cations, but depended mainly on the available supply of K. However, the application of K greatly reduced the absorption of Ca, Mg, and Na.

There are many references in the literature to Mg deficiency caused by K fertilisation. Walsh and O'Donohoe (153) grew potatoes, tobacco, sugar beet, wheat, barley and oats in a peat-sand mixture in pots, to determine the extent to which Mg deficiency could be induced by K. K was applied at 100, 1,000 and 10,000 ppm K_2SO_4 relative to the peat-sand mixture. The high levels/

levels of K reduced the Mg content and total Mg uptake of all crops studied, and caused Mg deficiency symptoms to appear in all crops except wheat. Mg deficiency symptoms, which were obvious in the foliage of potatoes, were not reflected in the Mg content of the tubers, but the yield was reduced. Soil samples were collected from a number of areas growing crops showing Mg deficiency symptoms and the authors stated that none of the soils was deficient in exchangeable Mg, while exchangeable K was high in every case (> 60 mg K/100g soil). The lowest exchangeable Mg content found was 12 mg / 100g soil, but the authors did not quote levels of exchangeable Mg likely to be found in "Mg-deficient" soils.

In a study of the Mg status of 20 New Jersey soils, Prince et al. (109) concluded that the most important single factor influencing the Mg uptake of plants was the amount of available K. As the K supply in the soils decreased with repeated harvests of alfalfa, the Mg content of the plant increased even where the exchangeable Mg contents of the soils were very low (1.2 - 2.6 mg Mg/100g soil).

Several workers have found that leaves from Mg deficient apple trees were high in K even when the exchangeable K content of the (surface) soil was low, and that high K fertilisation on soils low in Ca and Mg induced Mg deficiency or increased its severity (15, 47, 67, 136, 150). Boynton and Burrell (14) suggested that the effect of K was due to competition at the root surface or within the tree. K applied over a period of years increased exchangeable K in the soil and decreased exchangeable Ca and Mg, although much of the decrease in Ca and Mg which occurred in that time was due to continual use of Sulphur sprays and $(NH_4)_2SO_4$.

In experiments by Cain (19), the absorption of K and Mg by apple trees in/

in sand culture was governed almost entirely by the available supplies. Neither K nor Mg significantly affected the rate of absorption of the other, as measured by depletion of the nutrient solutions. However, a high level of either often resulted in a reduced concentration of the other in the leaf. Cain suggested that these effects were due to growth and translocation phenomena and that the antagonism between K and Mg occurred within the plant and not during absorption.

The antagonistic effect of K applications on Mg uptake by pasture plants has been observed by many authors (42, 43, 108, 138, 155, 161). The antagonism becomes important for plant growth only if the Mg content of the herbage is reduced below the level required for optimum growth. However, this level of Mg may not be sufficient to meet the Mg requirements of the grazing animal. There is much evidence to show that a low Mg content in the diet of ruminants is related to the incidence of hypomagnesaemia (8, 66, 98, 116, 117, 119, 135, 139).

The literature on hypomagnesaemia is very extensive and a review is not relevant here. Various aspects of the subject were discussed at a British Veterinary Association Conference on Hypomagnesaemia (17), and a more extensive review of the literature on the role of Mg in the nutrition of farm animals has been published by Rook and Storry (118).

Walsh and O'Donohoe (153) reported a direct relationship between the severity of Mg deficiency symptoms in crops and the foliage K content, at a particular low level of Mg in the foliage. Nearpass and Drosdoff (95) found a highly significant negative correlation between the Mg content of tung tree leaves and the exchangeable K content of the soil.

The/

The results of 39 simple field manurial experiments with oats on a sandy soil carried out by Ferrari and Sluijsmans (29), showed that, as the level of "available" K in the soil increased, the Mg content of oats decreased. The severity of Mg deficiency symptoms at the same level of exchangeable Mg in the soil increased with increasing "available" soil K content, and presumably with the K contents of the plants, although these were not determined. An application of KCl (90 lb K/acre) increased the severity of the Mg deficiency symptoms (especially where the soil Mg content was low or where no Mg was applied), but at the same time, the Mg content of the oats was slightly but significantly increased. Ferrari and Sluijsmans suggested that the increased severity of the Mg deficiency symptoms following K fertilisation occurred because the increase in leaf K content was probably relatively greater than the increase in Mg content.

Knoblauch and Odland (68) found that where no Mg was applied, continual application of high levels of K (giving a total of 1,200 lb K/acre in 8 years) reduced the yield of tubers and intensified Mg deficiency in potatoes growing on an acid silt loam (pH 5.1 - 5.3). They explained this on the grounds that ion antagonism made the absorption of Mg more difficult, and that Mg displaced from the base exchange complex in the soil by K was lost by leaching. Increased Mg content of drainage water has been noted after application of K fertilisers (49, 50, 121). In laboratory leaching studies with various soils, Hogg (50) reported that application of K as KCl or K_2SO_4 resulted in considerable loss of Mg in the drainage water, particularly from sandy soils, but when the same quantity of K was applied as K_2CO_3, $KHCO_3$, or KH_2PO_4 very little loss occurred.

Applied/

Applied Mg, or a high soil Mg content (relative to K) results in low K content of plants and in some cases causes the appearance of K deficiency symptoms (34, 57, 89, 123, 153). Walsh and O'Donohoe (153) found K deficiency in potatoes caused by a high exchangeable Mg content (136 mg Mg/100g soil) in a soil not particularly low in exchangeable K (27 mg K/100g soil). Addition of $MgSO_4$ accentuated the K deficiency.

K-Mg antagonism has been observed by other investigators in many crops, both in field experiments as well as in sand and solution cultures (23, 52, 56, 62, 126, 142, 152, 157).

Total Mg uptake by plants may be increased, despite a reduction in Mg content, if applied K increases crop yield. For example, Perkins and Stelly (101) found that the Mg contents of oats and crimson clover were decreased by K, but the beneficial effect on yield resulted in an increased total Mg uptake by clover.

Symptoms of Mg deficiency are not necessarily accompanied by lower crop yields. Foy and Barber (30) reported the appearance of Mg deficiency symptoms induced by K but not accompanied by a reduction in yield of maize grown on an acid sandy loam (pH 4.7). An application of $MgSO_4.7H_2O$ prevented development of the symptoms, significantly increased Mg content and decreased K content of the leaves, but did not increase yield. From observations on field trials, Ferrari and Sluijsmans (29) found that oats showing mottling symptoms, but still having a general green appearance, did not suffer from a decrease in final yield. More severe Mg deficiency symptoms were associated with lower yields.

The general conclusion drawn from the literature quoted is that K influences/

influences the magnesium nutrition of plants in two main ways.

Firstly, K is antagonistic towards the Mg ion and application of K to the soil, by inhibiting Mg absorption, may reduce plant Mg content. Competition between K and Mg may also occur within the plant. Reduction in Mg content is not necessarily accompanied by reduced total uptake of Mg if K application also increases yield.

Secondly, K applications may reduce the amount of available Mg in the soil by increasing the loss of Mg in the drainage water.

2. Mg and Ca.

One of the first ion interactions observed was that between Mg and Ca Loew and May (73) reported that a large excess of either nutrient was harmful to plants, and presented evidence in support of the "lime-magnesia" hypothesis, already put forward by Loew, which stated that, for optimum plant growth, there should be a definite ratio of available Ca to Mg in the soil: this ratio was different for different plants.

Loew's hypothesis was supported by a number of other workers, but Moser (88) found no correlation between crop yields and Ca:Mg ratios in the soil varying from 1:1 to 4.5:1, and Hunter (54) reported that variations in the Ca:Mg ratio from 32:1 to 1:4 had no effect on the yield of alfalfa. Lipman (72) concluded from a critical review of the literature that there was little evidence to show that a definite Ca:Mg ratio was necessary for the optimum growth of plants. However an application of either Ca or Mg to the soil may depress the uptake of the other as found by Halstead et al. (36). Raising the pH of various acid soils to neutrality by addition of $MgCO_3$ decreased/

decreased the exchangeable Ca in the soils and, except in an uplands sand, the addition of $CaCO_3$ reduced the exchangeable Mg. Treatment with $MgCO_3$ reduced the Ca content of plants grown on these soils to a greater extent than $CaCO_3$ reduced the Mg content.

In a greenhouse pot experiment carried out to test the assumption that low Mg content of citrus tree leaves may be caused by high ratios of Ca to Mg in the root medium, Jacoby (61), using a split-root technique, showed that the low Mg content was due, not to low Mg content of the soil, but to excess Ca. Michael (84) found that absorption of Mg was dependent on the level of available Ca in the soil: excess of either Ca or Mg depressed the content of the other in plants. Similar results have been obtained from sand culture experiments with rubber (12) and tobacco (142).

In experiments by Parr and Allcroft (98), application of 10 cwt/acre calcined magnesite to pasture growing on a light sandy soil of "fairly low lime status" increased the pasture Mg content to a greater extent than 50 cwt magnesian limestone which supplied the same amount of Mg. They suggested that the difference was due to antagonism of the Ca present in the magnesian limestone. The pasture treated with the calcined magnesite has a lower Ca content. Similar results have been obtained by other workers (34,161).

Plant (107) reported that applications of $CaSO_4$ to the soil reduced the Mg content and accentuated Mg deficiency in oats, barley, kale, potatoes, and sugar beet. Mehlich and Reed (82) reported that addition of $CaSO_4.2H_2O$ to pots of uncropped soil resulted in increased loss of Mg when the soil was leached with distilled water. The Mg content and total Mg uptake of cotton grown/

grown on the leached soil was reduced where $CaSO_4.2H_2O$ had been added. Willis (160) also found that application of $CaSO_4.2H_2O$ to soil increased the loss of Mg by leaching.

Reduction of exchangeable Mg in the soil and loss of Mg in the drainage water following application of superphosphate has been reported. Dixon and Taylor (28) attributed the reduction to the action of the $CaSO_4$ present in the superphosphate. The results of laboratory leaching studies by Hogg (50) support this suggestion. Where superphosphate was replaced by "double" superphosphate (which contains no $CaSO_4$) the loss of Mg by leaching was reduced to a negligible level.

Where Ca is added to the soil in a neutral salt such as $CaSO_4$, the Ca-Mg antagonism is clearly shown, but Ca is often applied in some form of lime (eg. $CaCO_3$, $Ca(OH)_2$, CaO) which, by raising the pH of the soil causes many effects not directly attributable to Ca. A distinction must be made between the effects of added lime on the soil, and the direct effect of Ca on the absorption of Mg by plants.

There are many instances reported in the literature of applied lime increasing the Mg content of plants, despite Ca-Mg antagonism (1, 10, 40, 56, 70, 102, 110, 111, 157). In many cases where this occurred the soils were acid and the pH was greatly increased by liming, so that the effect of pH on Mg absorption must also be considered.

3. Mg and H.

The H ion is antagonistic towards Mg, but the direct effect of pH appears/

appears to be important only at extremes of acidity and alkalinity. In experiments by Wadleigh and Shive (152) with maize, and by Arnon et al. (4, 5) with tomato, lettuce and Bermuda grass, the Mg absorbed from culture solutions was greatly reduced at pH 3, but variations in the reaction of the culture solution between pH 4 and pH 8 had little effect, provided that an adequate supply of all nutrient elements was maintained. Michael (84) found that the uptake of Mg from culture solutions by young maize and rye plants was considerably lower at pH 4 than at pH 6 or 7.5. Schropp (128) observed that Mg deficiency occurred more often in plants grown in Richter's culture solution (pH 4.29 - 4.63) than in Crone's solution (pH 5.27 - 6.71).

Mg deficiency has been most commonly reported in acid soils, especially those of a light texture (1, 18, 20, 55, 69, 84, 90, 102, 129, 133). This is to be expected, as high soil acidity is generally the result of loss of bases by leaching. Balks (7) noted Mg deficiency in a heavy soil which he attributed to high acidity (pH 4.9).

Not only are acid soils often low in Mg, but added Mg can be leached out more readily than Mg from neutral soils. In laboratory experiments, Magnitskiĭ and Malkov (79) found that leaching of Mg (applied as $MgSO_4$) from artificially acidified soils was much greater than from the corresponding untreated soils, and Peech (99), who treated a series of samples of acidified sandy soil with increasing amounts of $Ca(OH)_2$ to give a pH range of 3 to 8, found that as pH increased, the leaching loss of Mg (applied as $MgCl_2$) decreased. Willis (160) reported that, in 2 loam soils to which calcitic limestone had been applied, the solubility of Mg and loss of/

of Mg from the soils by leaching were lower than in the corresponding unlimed soils.

Morgan et al. (87) and Schmitt (127) reported that loss of Mg was greater where applied fertilisers had increased soil acidity. Smit and Mulder (133) found no reduction in available Mg (as measured by Aspergillus niger) after 10 weeks storage of moist samples of a fertile sandy soil which had been treated with increasing amounts of H_2SO_4, showing that Mg was not fixed in unavailable form. (The actual Mg content of the soil was not stated.) On leaching the soil with distilled water, nearly all the Mg was lost, indicating that the harmful effect of low pH consisted of leaching of the available Mg.

Several investigators (32, 84, 127) had earlier suggested that Mg might be fixed in unavailable forms at low pH levels, but no evidence was presented to support this suggestion. Fixation of Mg occurs at high pH, in soils with high Mg and clay contents, rather than in light acid soils where Mg deficiency is most common (65, 76, 109, 137). MacIntyre et al. (76) studied Mg absorption by a loam soil in lysimeter units leached by rainfall for a period of 4 years after applications of Mg, both as MgO and $MgCO_3$, at rates equivalent to 8 and 32 tons/acre CaO. The higher applications of Mg resulted in greater absorption of Mg in non-exchangeable form: the absorption took place at about pH 9. The Mg fixed in non-exchangeable form could be readily removed from the soil by leaching with dilute acid. Kardos and Joffe (65) demonstrated fixation of Mg into complex synthetic silicates at pH values of 8.5 and over, and Stephen (137) suggested that Mg might be fixed at high pH by a reversal of the/

the process of weathering of chlorite to vermiculite (which normally takes place below pH 5). In a study of the Mg status of 20 New Jersey soils, Prince et al. (109) found that soils which fixed Mg contained relatively large amounts of the element in exchangeable form, and that fixation was increased by application of $MgSO_4.7H_2O$.

Bower and Turk (13) reported that Ca and Mg deficiencies may result from a high content of exchangeable Na (more than 40% Na saturation) in alkali soils, and in calcareous alkali soils if the pH is very high (>9). Under such conditions, the solubility of Ca and Mg may be very low.

Ferrari and Sluijsmans (29) reported that an increase in soil acidity below pH 4.8 promoted Mg deficiency symptoms and decreased the Mg content of oats growing on a sandy soil, if the exchangeable Mg content of the soil was lower than 2.1-2.4 mg/100 g soil. The results of pot experiments with oats grown in acid soils (pH 4.1 - 4.3), where symptoms of Mg deficiency had occurred in the field, confirmed earlier observations by van Itallie (55) that plants growing on these soils suffered from other effects of acidity as well as from shortage of Mg (56).

There are many instances reported in the literature of applied lime increasing plant Mg content, and Mg deficiency symptoms were sometimes reduced or eliminated following liming (1, 10, 40, 56, 70, 102, 110, 111, 133, 157), but investigators do not agree as to the nature of the beneficial effects. Liming would certainly remove excess H ions from direct competition with Mg, but the function of lime may be to increase soil microbiological activity (including nitrification) or to improve plant growth which had been restricted by the secondary effects of acidity, such as/

as lack of available Ca and P or the presence of toxic amounts of Al and Mn (27, 71, 87, 90, 92, 133).

Smit and Mulder (133) grew oats in pots of sand-peat mixture to which pure $CaCO_3$ had been added to give a pH range of 3.5 - 6.8. At pH 3.5 and 4.2, there was very poor growth and little response to added Mg. Growth was normal, and there was a good response to Mg, at pH 4.6 - 6.8. In experiments with culture solutions, Smit and Mulder (133) found that the response of oats to Mg was greater at pH 6.0 - 6.5 than at pH 4.0 - 4.5, and attributed this to poor root development in the acid culture. After 8 weeks, by which time root growth in the acid culture had improved and "fairly good" root systems developed, the oats were given extra Mg. The response was similar in both cultures, so that neither uptake of Mg nor its assimilation by the plant appeared to be impaired by excess H ions. The authors concluded that the poor development of oats in acid solution was probably due to insufficient root development.

Addition of lime to the soil may mobilise Mg so that it becomes more readily absorbed by plants or lost by leaching. Increased Mg content of drainage water has frequently been noted after the application of lime and other fertilisers (23, 28, 49, 50, 74, 82, 88, 121, 160).

However, Smit and Mulder (133) found that, although plant development was better, there was no increase in available Mg (as measured by Aspergillus niger) after the addition of pure $CaCO_3$ to acid soils. In lysimeter and cylinder experiments, Moser (88) found that the addition of pure $CaCO_3$ to various acid soils, increased only the exchangeable Ca content of the soil and had no effect on the exchangeable Mg. In one experiment, the/

the addition of limestone slightly increased the exchangeable Mg content of the soil, but in this case, the limestone contained Mg as an impurity. It has been pointed out by other workers, that the increase in the Mg content of plants following liming may be due to the addition of Mg as an impurity in the lime (29, 133).

In an experiment by Welte and Werner (157) with an acid sandy soil deficient in Mg, increasing applications of KCl caused severe Mg deficiency symptoms and lowered the yield of oats, whereas the same levels of K applied as $KHCO_3$ increased Mg uptake and yield. (Details of the experiment were not given.) Welte and Werner suggested that the higher pH brought about by the addition of $KHCO_3$ reduced the H-Mg antagonism more than the K-Mg antagonism was increased: the antagonistic effect of the H ion on Mg absorption was apparently stronger than that of the K ion. However, the $KHCO_3$ treatment, besides removing the direct H-Mg antagonism, would also remove some of the secondary effects of soil acidity which restrict growth, and it is possible that more Mg may have been lost by leaching after the application of KCl, than after the $KHCO_3$ treatment (50).

In pot experiments, van Itallie (56) found that an application of K_2CO_3 which raised the pH of an acid soil from 3.9 to 5.3 was much less effective in increasing the yield of oats than an equivalent amount of $CaCO_3$ which raised the pH to 4.8. Application of $CaCO_3$ reduced the Mg deficiency symptoms and increased the Mg content of oats, while plants which received K_2CO_3 showed severe symptoms of Mg deficiency and had a lower Mg content.

The application of Mg salts, without raising the pH level has a favourable/

favourable effect on the Mg content, and in some cases on yield, of plants grown on acid soils (1, 29, 55, 56, 70, 102, 133). Smit and Mulder (133) reported that the addition of $MgSO_4$ reduced Mg deficiency symptoms and improved growth of oats despite high soil acidity (pH 4.8), but $CaCO_3$ was also required for optimum growth. Although the Mg level in plants growing on acid soils treated with $CaCO_3$ only was still fairly low, the total quantity of Mg taken up by these plants was considerably greater than that taken up by plants growing on untreated soils.

To summarise: low Mg uptake by plants growing on acid soils is more likely to be due to absolute shortage of Mg in the soil or to poor growth resulting from the secondary effects of acidity, rather than to the direct interference of H ions in the absorption of Mg by plant roots, except where acidity is very high (below about pH 4.5). Fixation of Mg does not appear to be a problem in acid soils but may occur at high pH levels.

4. Mg and N.

The form in which N is available greatly influences the absorption and utilisation of Mg by the plant. The NH_4 ion is antagonistic towards Mg (and other cations) and depresses the Mg content of plants as compared with N in the NO_3 form. This has been observed with barley (2, 3), wheat (124), maize (152), rice (59, 143), ryegrass (124), tobacco (75, 140, 141), citrus (83, 154), cotton (51) and rubber (12) in water or sand culture experiments. In many of these experiments, the investigators did not state whether or not any special precautions were taken to keep the cultures sterile and thus prevent nitrification of NH_4, although some workers reported that/

that nitrification did not occur (2, 154).

In all the experiments quoted above, the N was applied in the form of simple salts such as $Ca(NO_3)_2$ or $(NH_4)_2SO_4$. In order to eliminate the effects on plant absorption of the other ions which must necessarily be added with the NO_3 or NH_4 ions (eg. Ca in $Ca(NO_3)_2$), Welte and Werner (156) applied NO_3 and NH_4 bound to exchange resins to oats, rape and maize growing in sand culture. The influence of the form of N was clearly shown in the aerial parts of the plants, but not in the roots. As the proportion of NH_4 in the culture increased, the Mg contents of the stems and leaves decreased.

The papers mentioned above agree on the effects of NH_4 and NO_3 in solution and sand culture, but the position is not so clear when soil is used as the nutrient medium.

The beneficial effect of NO_3 on the Mg nutrition of potatoes has been shown by Marel and Broek (80), and Mulder (90). Mulder conducted a number of field experiments with potatoes on various acid soils (pH 4.7 - 5.3). N was applied at various rates in the form of $Ca(NO_3)_2$, $(NH_4)_2SO_4$ and $NH_4NO_3/CaCO_3$. Consistently higher yields were obtained from $Ca(NO_3)_2$ than from $(NH_4)_2SO_4$. The differences were much less noticeable where $MgSO_4.H_2O$ was also applied. $NH_4NO_3/CaCO_3$ gave results comparable to $Ca(NO_3)_2$, "due to its NO_3 content and nitrification of part of the NH_4." Mulder found in a number of cases that more severe symptoms of Mg deficiency occurred in the foliage of potatoes dressed with 57 lb Mg/acre as $MgSO_4.H_2O$ in the absence of added nitrogen, than in plants dressed with 125 lb N/acre as $NH_4NO_3/CaCO_3$ without added Mg.

In/

In pot experiments with acid soils (pH 4.2 - 4.5) in which N was applied in several forms including $Ca(NO_3)_2$, $NaNO_3$, NH_4Cl and $(NH_4)_2SO_4$, Pfaff and Buchner (102) found that use of nitrates resulted in greater uptake of Mg by oats than use of NH_4 salts. Similar results were obtained by van Itallie (55, 56).

In one of Mulder's experiments (90), wheat plants were grown in pots vertically divided into two parts, one half being filled with an acid sandy soil low in Mg (pH 5.1, and available Mg 1.7 mg/100 g soil as measured by Aspergillus niger), and the other half with a Mg-free mixture of sand and peat (pH 6.3). $(NH_4)_2SO_4$ applied to either side of the pot, caused the appearance of Mg deficiency symptoms, but where the N was applied as $Ca(NO_3)_2$, the symptoms appeared only when it was applied to the sand and peat. The small amount of Mg in the soil was taken up only in the presence of NO_3. In other experiments (90), wheat and oats grown in pots of acid soil (pH 5.2) with and without added Mg, at different levels of $Ca(NO_3)_2$, $NaNO_3$, NH_4NO_3 and $(NH_4)_2SO_4$, became increasingly deficient in Mg with increasing applications of $(NH_4)_2SO_4$, where no Mg was added. No deficiency was noted with $Ca(NO_3)_2$ and $NaNO_3$, while NH_4NO_3 took an intermediate position. Similar results were obtained in field experiments with wheat, oats and maize.

Although the NH_4 ion is antagonistic towards Mg and application of NH_4 fertilisers reduces the Mg content of plants, there may be an increase in total Mg uptake if a large increase in yield results from the fertiliser application.

Apart from the direct antagonistic effect of the NH_4 ion, application of/

of $(NH_4)_2SO_4$ over a period of time reduces soil pH and increases the loss of Mg by leaching (9, 11, 14, 56, 71, 87, 90, 103, 161).

The depressing effect of NH_4 salts on the Mg content of crops has been noted by many other authors (58, 62, 64, 106, 151), but applications of $(NH_4)_2SO_4$ have been found, under certain conditions, to increase not only total Mg uptake but also Mg content of grassland (42, 43, 119, 148, 161), fruit tree leaves (11, 16), and other crops (41, 102, 158).

A study of the effect of N on mixed herbage is complicated by its influence on botanical composition. Clovers and herbs usually have a higher Mg content than grasses grown under identical conditions (8, 21, 63, 144, 145, 148, 161), and application of N, by suppressing clover growth may reduce total Mg uptake by the herbage, although the Mg contents of the individual species may be increased (43, 138, 155, 161). Similarly the application of K, especially where available K in the soil is low, may increase total Mg uptake by the herbage through stimulation of clover growth, in spite of the antagonistic effect of K towards Mg (53, 77, 113, 138).

The reason for the differences in the effect of NH_4 when applied to the soil may be found in the induced soil pH differences and the consequent effects of pH on nitrification. The conversion of NH_4 to NO_3, which proceeds rapidly in neutral soils is inhibited by acidity (27, 71, 87, 92). In their reports, some investigators did not state the pH of their experimental soils, but, when given, the pH values were usually low (pH 4.0 - 5.5) where NH_4 reduced plant Mg content, whereas the soils in which NH_4 increased Mg content were usually neutral or only slightly acid. This/

This suggests that the beneficial effect on Mg absorption of NH_4 applications in neutral soils may, in fact, be a nitrate effect resulting from enhanced nitrification. Dijkshoorn (27) found in pot experiments that applied $(NH_4)_2SO_4$ was completely nitrified at pH 7 within 21 days. Nitrification was considerably slower at pH 5.3 and completely inhibited at pH 4.3. At pH 7, the Mg content of perennial ryegrass was the same for both forms of applied N, but as the pH decreased, NO_3 applications increased the Mg content, while NH_4 applications reduced the Mg content. Will (158) found that small applications (2 cwt/acre) of $(NH_4)_2SO_4$ increased the Mg content and prevented chlorosis due to Mg deficiency in pine seedlings growing in pumice soil nurseries (pH 5.0), but that higher rates of application increased the chlorosis. He suggested that, "under suitable conditions," low rates of applied NH_4 may be quickly nitrified, and that the increased plant Mg content resulting from the application is a nitrate effect.

One of the aims of the present series of experiments was to determine whether or not the increased plant Mg content sometimes found after application of $(NH_4)_2SO_4$ to the soil is a nitrate effect following nitrification of the NH_4.

III. EXPERIMENTAL METHODS AND MATERIALS.

The experimental programme, conducted in seasons 1961 - 1963, consisted of —

1. A factorial field experiment with barley grown on a loam soil (pH 5.5) with different levels of added limestone and N (applied either as $(NH_4)_2SO_4$ or $NaNO_3$).

2. A factorial pot experiment with oats grown under normal atmospheric conditions on 2 sandy loam soils (pH 5.7 and 7.6). The fertiliser treatments included different rates and combinations of $Ca(NO_3)_2$, $(NH_4)_2SO_4$, KCl and $MgSO_4.7H_2O$.

3. A factorial experiment with oats grown in pots of acid sandy soil (pH 4.6) under normal atmospheric conditions. The treatments consisted of different levels of $CaCO_3$ and $MgSO_4.7H_2O$, with N applied either as $(NH_4)_2SO_4$ or $Ca(NO_3)_2$.

A. Field Work.

1. BARLEY - FIELD EXPERIMENT (1962).

Site.

The site, chosen on the basis of uniformity of both the physical and chemical properties of the soil, was at Baberton Mains, Currie, Midlothian. The top soil was a reasonably uniform loam overlying a variable sandy loam - sandy clay loam subsoil. The parent material was semi-sorted till derived from lower carboniferous cement stones, sandstones, oil shale, coal, and occasional basic igneous rocks. The experimental area was very gently undulating./

undulating. Drainage was imperfect; uniform. Barley was grown in the previous season.

The results of chemical analysis of 72 soil samples taken from the individual plots at the beginning of the experiment are summarised in Table 1. (The methods of soil analysis are described on pages 47 - 54.)

Table 1. Barley experiment: summary of initial soil analysis.

Sampled 18 Dec 61	pH	"Available" nutrients (mg/100 g soil)		
		P	K	Mg
Mean of 72 samples	5.5	0.34	5.0	6.6
Standard deviation ±	0.12	0.075	1.1	1.0
Coefficient of variation (%)	2.19	22.3	22.0	15.1

Total Mg content = 0.54%
Loss on ignition = 7.62%
} Single determinations carried out on a bulked sample.

Design and Treatments.

The experiment was a 3 x 3 x 2 factorial arranged in 3 blocks of 6 plots (each 20 sq yd in area). The treatments were —

Ca - 0, 30, 60 cwt ground calciferous limestone/acre.

N - 0, 35, 70 lb N/acre either as

T - $(NH_4)_2SO_4$ or $NaNO_3$

The limestone (33.0% Ca, 1.3% Mg, neutralising value ≡ 83.6% $CaCO_3$) was applied at rates equivalent to 0, ½ lime requirement, and full lime requirement to pH 6.5. All plots received a basal dressing of potassic superphosphate/

superphosphate equivalent to 20 lb P and 20 lb K/acre.

There were 4 replicates and the arrangement of the plots was such that the lower order interactions were partially confounded. The 3 blocks were arranged at random within each replicate, and the plots arranged at random within each block. The analysis of variance was as follows --

	Degrees of freedom.
Replicates	3
Blocks within replicates	8
T	1
N	2
Ca	2
CaT	2
NT	2
CaN	4
CaNT	4
Error	43
Total	71

The lay-out of the experiment is given in Appendix II, Table 24.

Cultivations and Sowing.

Half of the ground limestone dressing was broadcast by hand on the surface of the soil on 18 Dec.1961. Ploughing was carried out during January, and the remainder of the ground limestone was applied on 21 Feb.1962. The field was cultivated and barley (var. Ymer) was drilled on 26 March. Later the same day, the fertilisers were broadcast by hand on/

on the surface of the soil and harrowed in. The barley emerged evenly about 18 - 20 April, and the field was rolled 3 weeks later. When cultivations were complete, the boundaries of the plots were marked with canes.

Barley Sampling.

The barley was sampled at 5 stages of growth —

1.	3 - 4 leaf stage	22 May
2.	5 - 6 leaf stage	7 June
3.	Before "heading"	22 June
4.	After "heading"	3 July
5.	Maturity	13 Sept.

Sampling was carried out by cutting the barley about 1 in. above the soil surface. Plants were taken at random from the plot, a few at a time, except from an area 2 ft wide around the perimeter, which was used as a guard area. The weight of the fresh material sampled varied from about 100 - 150 g at the first sampling to over 600 g at later samplings. Samples were collected in polythene bags and immediately taken into the laboratory where the fresh weights were recorded. The plants were dried overnight at 100°C in an electric oven with an extraction fan, and reweighed. The samples were then milled, and stored in plastic containers until analysed for total Ca, Mg, P, K and Na contents.

Because of the wet conditions under which the last sampling had to be carried out, no percentage dry matter determination was attempted. At this sampling, the barley was separated into grain and straw fractions.

An/

An estimate of the sampling error is given in Table 4 (p 46).

Soil Sampling.

When the experiment was first laid down (18 Dec.1961), and after the barley had been harvested (26 Sept.1962), soil samples were taken from each plot for determination of pH, and "available" P, K and Mg contents.

The soil was sampled in the field by means of a soil auger to a depth of 8 - 9 in. About 12 - 15 cores were taken and bulked to give a composite sample of about 2 lb representative of the area. In the laboratory, the soils were air dried, and passed through a 2 mm sieve in preparation for analysis.

In addition, soil samples were taken from all plots 5 times during the season for the determination, on the fresh soil, of mineral N content, both NH_4 and NO_3. The fresh moist soil was passed through a $\frac{1}{4}$ in. mesh riddle to remove stones and vegetation. Samples from the four replicates of each treatment were bulked and nitrogen determined in the composite sample.

An estimate of the soil sampling error is given in Table 7 (p 57).

2. OATS - POT EXPERIMENT. 1962.

Design and Treatments.

The experiment was a $3^3 \times 2^2$ split-plot factorial, without replication. Two soils (S) were used, and the fertiliser treatments were --

Mg - 0, 60, 120 lb Mg/acre as $MgSO_4.7H_2O$

K - 0, 40, 80 lb K/acre as KCl

N - 0, 40, 80 lb N/acre either as

T - $(NH_4)_2SO_4$ or $Ca(NO_3)_2$

All/

All pots received a basal dressing equivalent to 25 lb P/acre as $NaH_2PO_4.2H_2O$. Technical grade chemicals were used for all fertilisers and the weight added to each pot was calculated on the basis of 2×10^6 lb soil/acre.

The pots were arranged in 3 blocks with 36 pots in each. The blocks were divided into 9 sub-blocks arranged at random within the block. Each sub-block consisted of 4 pots with the same level of N, K, and Mg application, but each pot within the sub-block had a different combination of the 2 soils and 2 types of N. These pots were arranged at random within the sub-blocks. The analysis of variance was as follows --

(a) Main treatments	Degrees of freedom
Blocks	2
N	2
K	2
Mg	2
NK	4
NMg	4
KMg	4
Error (a)	6
Total	26

(b) /

(b)	Sub-treatments	Degrees of freedom
	Main treatments	26
	S	1
	T	1
	ST	1
	SN	2
	SK	2
	SMg	2
	SNK	4
	SNMg	4
	SKMg	4
	TN	2
	TK	2
	TMg	2
	TNK	4
	TNMg	4
	TKMg	4
	Error (b)	42
	Total	107

This design was repeated 4 times, one for each of 4 samplings to be taken throughout the season. The layout of the experiment is given in Appendix III, Table 36.

Preparation of Pots./

Preparation of Pots.

The soils were taken from 2 adjoining long-term grass fields on Boghall Farm, Bush Estate, Milton Bridge, Midlothian. They were sandy loams derived mainly from colluvial material from andesite formations farther up the Pentland Hills, together with some glacial drift from mixed Carboniferous and Old Red Sandstone formations.

The soils were dug by spade to a depth of about 8 in. The top inch, consisting mainly of undecomposed vegetation, was discarded, and the remainder of the soil was passed through a $\frac{1}{4}$ in. mesh riddle to remove large stones and vegetation. The soils were kept in a moist condition until required, in order to maintain the microbiological population and to facilitate rewetting. Before use, the soils were mixed with an equal weight of coarse sand to facilitate drainage and aeration. The results of chemical analysis of the soil/sand mixtures are given in Table 2.

Table 2. Oats - pot experiment (1962): initial soil analysis.

Soil/sand mixture	pH	"Available" nutrients (mg/100 g soil)			Total Mg† %	Loss on ignition %
		P	K	Mg		
A	7.6	0.42	5.7	11.7	0.82	4.5
B	5.7	0.18	9.7	6.1	0.56	5.5

†Soil only

The pots were made of fireclay (8 in. diameter, 8 in. deep) coated on the inside with waterproof bituminous paint. A piece of "crock" was used to/

to cover a central drainage hole in the bottom of each pot.

4 pots receiving the same treatment were prepared simultaneously by mixing 30 lb moist soil with 30 lb coarse sand. The mixture was spread out on strong brown paper and the fertilisers (in solution) were sprinkled over the soil. The quantities applied were calculated for the weight of the mixture of soil and sand. All the fertilisers were applied together in one solution, except P which was added separately. The fertilisers were thoroughly incorporated with the soil/sand mixture and 14 lb of the mixture was weighed into each of the 4 pots, leaving 4 lb for "spillage". The soil was packed by lightly "dumping" the pots.

Sowing and Sampling.

Forty oat seeds (var. Blenda), dressed with an organo-mercurial fungicide, were sown per pot on 27 March at a depth of 1 in. below the soil surface. The pots were then arranged in a wire cage, open to atmospheric conditions (Plate 1), and watered to field capacity. Additional water was given by aerial spray throughout the season, when rainfall was not sufficient to keep the soil wet. The plants emerged evenly about 18 - 20 April, and at the 2 leaf stage, they were thinned to 30 plants/pot.

On 27 May, an additional top dressing of N, equal to the original amount given, was applied (in solution) to the surface of the soil in the remaining pots and watered in.† Symptoms of N deficiency had appeared

† This means that oats sampled after 27 May received a total N application equivalent to 0, 80 and 160 lb/acre, but in order to avoid confusion, the levels of N referred to in the presentation and discussion of the results are the initial applications of 0, 40 and 80 lb/acre.

rapidly over the previous few days. and were probably caused by leaching of N, following continual heavy rainfall during the week after sowing.

The oats were sampled at 4 stages of growth —

1.	3 - 4 leaf stage	18 May
2.	5 - 6 leaf stage	11 June
3.	Before "heading"	23 June
4.	After "heading"	3 July

Sampling was carried out by cutting the oat plants ½ in. above the surface of the soil, all the plants in the pot being removed. The oats were weighed immediately after cutting, and dried overnight at 100°C in an electric oven with an extraction fan, after which the dry weight was recorded. The samples were milled and stored in plastic containers until analysed for total P, K, Na, Ca and Mg contents.

Soil samples were taken for the determination of pH and "available" P, K and Mg contents, from the last series of pots just after the final sampling of the oats (4 July). The soils were put through a ¼ in. mesh riddle to remove roots, and were thoroughly mixed before sampling, to ensure that a representative sample was obtained.

3. OATS - POT EXPERIMENT. 1963.

Design and Treatments.

The experiment was a 4 x 3 x 2 factorial with 2 replicates. The treatments were —

Ca - 0, 33.3, 66.7, 100 cwt $CaCO_3$/acre.

N - 0, 90 lb N/acre as $(NH_4)_2SO_4$, 90 lb N/acre as $Ca(NO_3)_2$

Mg - 0, 80 lb Mg/acre as $MgSO_4.7H_2O$.

All/

All pots received basal fertiliser applications of $NaH_2PO_4.2H_2O$ equivalent to 20 lb P/acre, and KCl equivalent to 40 lb K/acre. Analytical grade chemicals were used for all fertilisers, and the weights added to each pot were calculated on the basis of 2×10^6 lb soil/acre.

The fertilisers (apart from $CaCO_3$) were applied in solution. The $CaCO_3$, P, K, and Mg treatments were mixed with the soil during the preparation of the pots. The N was added to the surface of the soil in the pots, in 3 equal applications during the season.

The pots were arranged at random within the replicates. The analysis of variance was as follows —

	Degrees of freedom
Replicates	1
Ca	3
N	2
Mg	1
CaN	6
CaMg	3
NMg	2
CaNMg	6
Error	23
Total	47

The layout of the experiment is given in Appendix IV, Table 52.

Preparation of Pots./

Preparation of Pots.

The soil was an acid sand taken from an uncultivated mound of freely drained fluvio-glacial sand and gravel about 20 ft deep, overlying till of mixed Carboniferous origin.

The soil was dug by spade to a depth of about 12 in. The top 4 in., which consisted mainly of a mat of undecomposed vegetation, was discarded. The remainder of the soil was passed through a ¼ in. mesh riddle to remove vegetation and large stones. The soil was kept in a moist condition until use. The results of chemical analysis of the soil are as follows —

"Available" nutrients (mg/100 g air dry soil)

pH	P	K	Mg	Ca
4.6	0.35	8.7	1.6	9

Total Mg content = 0.28%

Loss on ignition = 4.1%

As the soil was very sandy, incorporation of coarse sand to facilitate drainage and aeration, as in the 1962 pot experiment, was unnecessary. The pots were prepared on 29 March by weighing out 28 lb portions of soil and thoroughly incorporating the $CaCO_3$, Mg, K and P treatments. 13 lb of the fertilised soil was placed in each of 2 pots which were lightly "dumped" to pack the soil. (The pots used were the same as those used for the previous pot experiment.) The pots were then arranged in a wire cage open to atmospheric conditions, and the soil watered to field capacity. Additional water was given by aerial spray throughout the season when rainfall was not sufficient to keep the soil wet.

Sowing and Sampling./

Sowing and Sampling.

On 8 April, 40 oat seeds (var. Maelor) dressed with an organo-mercurial fungicide were sown per pot at a depth of 1 in. below the soil surface. Later on the same day, the first N application was added in solution to the surface of the soil and watered in.

The plants emerged evenly on 24 April, and at the 2 leaf stage (9 May) they were thinned to 30 plants per pot. On 10 May, the second N application was added to the soil surface and watered in. The final N application was given on 27 May.

Symptoms of Mg deficiency, which appeared on oats in some pots, were evaluated on 29 May and just before sampling on 5 June, according to the scale of assessment used by Ferrari and Sluijsmans (29).

Scale.	Symptoms.
10	No mottling, plant quite sound.
9	Plant very faintly mottled.
8	Plant faintly mottled throughout: mottling especially on leaf edges.
7	Plant clearly mottled, but general appearance still green.
6	Plant strikingly mottled: connected dark spots on lighter background: plant yellowish green.
5	Plant considerably mottled: chlorophyll spots, largely detached on yellow background: plant greenish yellow.
4	Chlorophyll in great number of spots on yellow background: plant yellow.

3/

3 Plant clearly yellow with occasional distinct green chlorophyll spots.

2 Plant strikingly yellow: little chlorophyll left.

1 Plant completely yellow: no chlorophyll visible.

The oats were sampled on 5 June at the 4 - 5 leaf stage, and analysed for total N, P, K, Na, Ca and Mg contents. The soil was sampled on 6 June and analysed "fresh" for NH_4- and NO_3-N, and after drying for pH and "available" K, Mg and P contents. The sampling procedure for the oats and soil, and the treatment of the samples were the same as for the previous pot experiment.

B. Analytical Methods.

1. PLANT ANALYSIS.

Digestion of Plant Material.

A mixture of HNO_3 and $HClO_4$ was used to prepare extracts for the determination of total Mg, Ca, K, Na and P in plant material. Digestions and determinations were carried out in duplicate.

Reagents:-

Conc HNO_3 (sp. gr. = 1.42)

60% $HClO_4$ (sp. gr. = 1.54)

Procedure:-

Two ml conc HNO_3 were added to a 0.5 g sample of plant material in a 50 ml graduated Pyrex test tube. The sample was allowed to stand in HNO_3 overnight, and then the tube was gently heated until the material disintegrated. Two ml 60% $HClO_4$ were added and the heating continued, gently/

Plate 1. General layout of the 1962 oat experiment.

Plate 2. Plant digestion apparatus.

gently at first, until the liquid was colourless and all the HNO_3 was driven off. After cooling slightly, about 45 ml hot distilled water were added. When cold, the volume was made up to 50 ml in the digestion tube, and the digest filtered through a Whatman No.44 (15 cm) paper. After dilution the digests were approximately 0.3N acid.

A micro-digestion apparatus was built to enable the simultaneous digestion of 20 samples of plant material (Plate 2). The framework of the apparatus was made from slotted angle-iron. A 750 W "Sunhouse" electric bar heater, with an added thermostatic control, served as the source of heat. The protective wire grid covering the silica-enclosed heating bar was bent to form a support for the bases of the digestion tubes. The tops of the tubes were supported by 2 glass manifolds through which the acid fumes were extracted by glass air-extraction pumps (Fisons Scientific Apparatus Ltd).

Determination of Total Ca.

The method used is based on that of Williams and Morgan (159).

Reagents:-

Ca standard solutions: A range of standards containing 0 - 200 ppm Ca in 0.3N $HClO_4$ was prepared, using $CaCO_3$.

Buffer solution: 125 g ammonium acetate was dissolved in distilled water and 25 ml NH_4OH solution (sp.gr. = 0.88) added. The solution was diluted to 1.5 l with distilled water.

4% ammonium oxalate solution in distilled water.

0.04N HNO_3

Procedure:-/

Procedure:-

A standard graph was prepared. 5 ml aliquots of the standard solutions were pipetted into 12 ml conical centrifuge tubes and 3 ml buffer solution were added to each. The tubes were heated in a water bath to 75°C, and 2 ml 4% ammonium oxalate solution were added. After heating for a further 30 min, the tubes were cooled and centrifuged at 2,500 rpm for 10 min. The supernatant liquid was poured off and the insides of the tubes dried with filter paper. The precipitates were dissolved in 10 ml 0.04N HNO_3, heating slightly to aid solution. The levels of Ca in the solutions were measured in the flame photometer, setting the instrument to zero with the "blank" and to 100 with the maximum standard.

Aliquots of the plant digests, made up to 5 ml with 0.3N $HClO_4$ were similarly treated. A 5 ml aliquot gives the maximum reading when the plant material contains 2% Ca. Included with each batch of unknowns were a "blank" and a maximum standard, which were used for setting up the instrument.

Determination of Total K.

K (and Na) in plant material were determined by use of an E.E.L. flame photometer (22).

Reagent:-

KH_2PO_4: range of standard solutions containing 0 - 50 ppm K in distilled water.

Procedure:-

A standard graph was prepared by passing the range of standard solutions/

solutions through the flame photometer, setting the instrument to zero with distilled water, and 100 with the maximum standard.

An aliquot of plant digest was diluted to 50 ml with distilled water, and the K content measured in the flame photometer. A 5 ml aliquot gives the maximum reading when the plant material contains 5% K.

Determination of Total Na.

Reagent:-

NaCl: range of standard solutions containing 0 - 5 ppm Na in distilled water.

Procedure:-

As for K. A 5 ml aliquot of digest diluted to 50 ml gives the maximum reading when the plant material contains 0.5% Na.

Determination of Total Mg.

Mg was determined by the titan yellow method of Young and Gill (164).

Reagents:-

$MgSO_4$: range of standard solutions containing 0 - 4 ppm Mg in distilled water.

10N NaOH

Titan yellow: 0.02% solution in distilled water, prepared as required.

Polyvinyl alcohol: 2% solution in distilled water (stored in a refrigerator).

Hydroxylamine hydrochloride: 1% solution in distilled water.

Compensating/

Compensating solution: This was made up by dissolving the following salts in about 500 ml water, containing 5 ml conc HCl, and diluting to 1 l.

1.263 g $CaCO_3$ + 25 ml N HCl

0.35 g $Al_2(SO_4)_3.16H_2O$

0.21 g $MnSO_4.4H_2O$

0.25 g $FeSO_4.7H_2O$

0.059 g $CuSO_4.5H_2O$

0.70 g $Na_3PO_4.12H_2O$

Mixed Reagent: This was prepared just before use by mixing equal volumes of compensating solution, polyvinyl alcohol and hydroxylamine hydrochloride.

Procedure:-

A 5 ml aliquot of digest was diluted to 50 ml with distilled water. An aliquot of the diluted digest was pipetted into a 50 ml Pyrex test tube and the volume made up to 5 ml with distilled water. The following reagents were then added in quick succession, mixing thoroughly after each addition —

3 ml mixed reagent

1 ml 0.02% titan yellow

2 ml 10N NaOH

The colour developed was measured in an E.E.L. colorimeter after 10 min., using Ilford filter 624 (540 mμ) setting the instrument to zero with distilled water. The standard solutions were treated similarly. A 5 ml aliquot of diluted digest gives the same reading as the maximum standard when the plant material contains 0.4% Mg.

Determination of Total P./

Determination of Total P.

P was determined by measuring the colour produced on formation of the phosphovanadomolybdate complex (38).

Reagents:-

KH_2PO_4: range of standard solutions containing 0 - 50 ppm P in distilled water.

Mixed Reagent: 25 g ammonium molybdate, $(NH_4)6Mo_7O_{24}.4H_2O$, were dissolved in about 800 ml distilled water. 1.25 g ammonium vanadate, NH_4VO_3, were dissolved in about 600 ml hot distilled water and, after cooling, 175 ml conc HNO_3 were added gradually while stirring. The molybdate solution was then added and the solution diluted to 2 l.

Procedure:-

A calibration curve was prepared. 10 ml mixed reagent was added to 10 ml aliquots of the standards in 25 ml graduated test tubes. The solutions were diluted to 25 ml with distilled water and thoroughly shaken. The colours developed were measured after about 30 min in an E.E.L. colorimeter using filter OB10 (425 mμ), setting the instrument to zero with distilled water.

Aliquots of plant digest were treated in the same manner. A 10 ml aliquot gives the maximum reading when the plant material contains 0.5% P.

Determination of Total N.

N was determined by the Kjeldahl method in which the organic matter is oxidised by sulphuric acid and the nitrogen converted to ammonia. The method incorporated the Gunning - Arnold and Winkler boric acid modifications (31).

Reagents:-/

Reagents:-

conc H_2SO_4

K_2SO_4

$CuSO_4.5H_2O$

50% NaOH (tech.) in water

Zinc (granulated)

4% boric acid in distilled water

N/14 H_2SO_4 in distilled water

Tashiro's indicator: prepared by mixing equal volumes of 0.2% alcoholic methyl red solution and 0.1% aqueous methylene blue solution.

Procedure:-

A sample of plant material was weighed into a dry 500 ml Kjeldahl flask. 5 g K_2SO_4 were added, followed by a few crystals $CuSO_4.5H_2O$ to act as catalyst, and 20 ml conc H_2SO_4. The flask was heated until the organic matter decomposed and the solution became clear. The digestion was then continued for 1½ hours.

The flask was allowed to cool, and the digest diluted by the addition of about 200 ml distilled water. 60 ml 50% NaOH were added to form a separate layer at the bottom of the flask. A piece of granulated zinc was added and the flask connected to the distillation apparatus and the contents mixed. The flask was heated gently and the distillation continued for 30 min. The NH_3 evolved was collected in 25 ml 4% boric acid (+ 25 ml distilled water) and measured by titration with N/14 H_2SO_4 using Tashiro's indicator.

A "blank" determination was carried out with every 50 determinations to/

to measure N in the reagents. Determinations were carried out in duplicate. Analysis of a 1 g sample gives a titration (less "blank") of 20 ml N/14 H_2SO_4 when the plant material contains 2% N.
(1 ml N/14 H_2SO_4 ≡ 1 mg N.)

Standardisation of Methods of Plant Analysis.

The scheme devised for the analysis of plant material enabled one person to analyse 40 samples in duplicate per week for total K, Na, Ca, Mg, and P contents. This included time for preparation of standard solutions and reagents, and also for washing apparatus. N determinations on these samples, which required separate digestions, took an additional 2 - 3 days.

The preparation of plant extracts and determination of K, Na, Ca, P and N presented no difficulties. In the determination of N, no special precautions were taken during the digestion to reduce any NO_3 in the plant material to NH_4. However, the amount of NO_3 present was likely to be very small compared with the total organic— and NH_4-N. Results of N determinations on samples of plant material show good agreement between the method used, and one in which salicylic acid and $Na_2S_2O_3$ were used to reduce all the NO_3(6) (Table 3).

Table 3./

Table 3. Determination of N in plant material.

Comparison with A.O.A.C. method (6).		N content %				Mean N content
Grass sample (1)	Proposed method	3.15	3.14	3.16	3.12	3.14
	A.O.A.C. method	3.15	3.14	3.16	3.15	3.15
Grass sample (2)	Proposed method	2.49	2.49	2.51	2.47	2.49
	A.O.A.C. method	2.49	2.50	2.50	2.49	2.49

Replicate analysis using the proposed method.	Oats	Rape
Mean %	3.75	2.06
Standard deviation ±	0.057	0.016
Coefficient of variation (%)	1.53	0.75

Mg determinations were carried out in batches of 10. The colour was developed at one minute intervals and measured at one minute intervals 10 minutes later. In order to obtain reproducible results it was essential to carry out exactly the same procedure for each determination and to shake thoroughly after the addition of NaOH. Because of day to day variations, a standard graph had to be prepared with each series of unknown determinations. Not all sources of titan yellow are suitable for the determination of Mg (24).

The standard graphs which were prepared for the Ca, K, Na and P determinations were checked after every 100 determinations, but they showed virtually no change with time.

The/

The methods of plant analysis were tested for recovery of elements added to 10 different plant materials before digestion. The following elements were added in solution to 50 ml graduated test tubes --

10 mg K as KCl

2.5 mg Ca as $CaCl_2$

1 mg Mg as $MgSO_4.7H_2O$

1 mg Na as NaCl

1 mg P as $(NH_4)_2HPO_4$

The solutions were evaporated to dryness overnight in an oven at 95°C. Samples of plant material (0.5 g) were then weighed into each tube and digested with HNO_3 and $HClO_4$. All digestions and analyses for recovery of added elements were carried out in duplicate.

The accuracy of the methods was estimated by 10 replicate analyses of 2 samples of plant material carried out at different times over a period of 3 months.

An estimate of the sampling error involved in the barley experiment was obtained by analysis once only for total P, K, Na, Ca and Mg contents of 10 different samples of barley taken at the same time from 1 plot 24 sq yd in area. (These estimates of sampling error also include analytical error.) A summary of the results of the sampling error estimations, replicate analyses, and recovery of added elements is given in Table 4. (The full results are listed in Appendix I, Tables 16 - 21.)

Table 4./

Table 4. Standardisation of the methods of plant analysis.

	Element	†Sampling error	Replicate analysis		% Recovery of added elements
			Oats	Rape	
	Mean %	3.08	1.00	2.51	99.9
K	Standard deviation ±	0.057	0.018	0.037	1.15
	Coefficient of variation (%)	1.86	1.76	1.47	1.15
	Mean %	0.054	0.115	0.061	100.25
Na	Standard deviation ±	0.003	0.004	0.002	1.36
	Coefficient of variation (%)	6.19	2.60	2.77	1.36
	Mean %	0.087	0.141	0.187	100.3
Mg	Standard deviation ±	0.004	0.005	0.005	1.16
	Coefficient of variation (%)	4.35	3.39	2.62	1.16
	Mean %	0,48	0.35	0.95	100.4
Ca	Standard deviation ±	0.024	0.008	0.016	2.63
	Coefficient of variation (%)	4.92	2.36	1.72	2.63
	Mean %	0.261	0.090	0.315	100.6
P	Standard deviation ±	0.005	0.002	0.002	1.39
	Coefficient of variation (%)	2.10	2.64	0.77	1.39

†Barley experiment.

2. SOIL ANALYSIS.

Determination of Soil Reaction.

Soil pH was measured in a 1:2.5 suspension of soil and water, using a glass electrode.

Determination of Lime Requirement.

The method used is based on that of Tovborg-Jensen (149), in which standard quantities of soil are allowed to come to as near equilibrium as is practicable with $Ca(OH)_2$ solutions of different concentrations (134).

Reagent:-

$Ca(OH)_2$ solution: Approximately 0.1N $Ca(OH)_2$ was prepared by shaking excess solid $Ca(OH)_2$ for 48 hours in a 2% solution of sucrose in distilled water, and decanting through a Buchner funnel fitted with a Whatman No.3 paper. A few drops of chloroform were added to prevent microbiological decomposition of the sucrose. This stock solution was diluted to exactly N/30 immediately before use.

Procedure:-

Two 20 g portions of soil were weighed into conical flasks and different volumes of N/30 $Ca(OH)_2$ solution were added. The volumes were made up to 50 ml with distilled water and a drop of chloroform was added to each flask. The flasks were shaken overnight, the pH of the suspensions measured, and a titration curve was plotted.

From the curve, the quantity of lime, in terms of cwt $CaCO_3$/acre, required to raise the pH of the soil to the required level was calculated. This figure was multiplied by a "field factor" of 4/3 as the amount of lime/

lime required to raise the soil pH in the field has been found by experiment to be greater than that required in the laboratory.

Soil Extraction.

Extracts for the determination of "available" P, K and Mg in the soil were obtained by the use of an ammonium acetate - acetic acid (pH 4.5) extracting solution (44), prepared by carefully adding 600 ml glacial acetic acid and 270 ml NH_4OH solution (sp. gr. = 0.88) to about 5 l. distilled water and diluting to 10 l. when cool.

Procedure:-

50 ml extracting solution were added to 10 g air-dry soil in a 100 ml shaking bottle (100). After shaking for 30 min the extract was filtered through a Whatman No.3 (15 cm) paper into a 100 ml conical flask.

Determination of "available" P.

Soil P was determined by measuring the blue colour produced after reduction of ammonium phosphomolybdate by $SnCl_2$ (24), using a method adapted from that of Peech and English (100).

Reagents:-

$NH_4H_2PO_4$: range of standard solutions containing 0 - 5 ppm P in extracting solution.

Molybdate reagent: 30 g ammonium molybdate, $(NH_4)_6Mo_7O_{24}.4H_2O$, were dissolved in 600 ml distilled water, and 1 l. conc HCl added slowly while shaking. After cooling 400 ml distilled water were added. The reagent was stored in a brown coloured bottle.

$SnCl_2$ solution: This reagent was prepared fresh when required, by dissolving/

dissolving 0.5 g $SnCl_2.2H_2O$ in 50 ml dil HCl (1 part conc HCl to 9 parts distilled water.)

Procedure:-

A 5 ml aliquot of soil extract was pipetted into a 50 ml beaker, 1 ml molybdate reagent was added and the solution mixed well immediately. Three drops of $SnCl_2$ solution were then added, and the solution again mixed well. The colour developed was measured after 15 min in an E.E.L. absorptiometer using filter 608 (660 mμ), setting the instrument to zero with distilled water. The colour is stable for 1 hour. The soil P content was determined from a standard graph prepared by treating a series of standards in the same way.

Determination of "available" K.

The "available" K content of the soil was determined directly on the soil extract, using the same method as that used for determination of K in plant material (22).

Reagent:-

KCl: range of standard solutions containing 0 - 100 ppm K in distilled water.

Determination of "available" Mg.

This method was developed in the Edinburgh School of Agriculture (24) from the titan yellow method of Yien and Chesnin (162) for use with ammonium acetate - acetic acid soil extracts. Mannitol has been substituted for polyvinyl alcohol as the stabilising agent.

Reagents:-/

Reagents:-

$MgSO_4$: range of standard solutions containing 0 - 12.5 ppm Mg in extracting solution.

N ammonium acetate.

10N NaOH

2.5% mannitol in distilled water.

0.04% titan yellow in distilled water, prepared as required.

Compensating solution: This was made up by dissolving the following salts in about 500 ml distilled water containing 14.7 ml conc HCl, and diluting to 2 l. with water —

2.5 g $CaCO_3$

0.74 g $Al_2(SO_4)_3.16H_2O$

0.4 g $MnSO_4.4H_2O$

0.6 g $Na_2HPO_4.12H_2O$

Mixed reagent: This was prepared just before use by mixing 1 part 2.5% mannitol solution with 2 parts compensating solution.

Procedure:-

1 ml soil extract was pipetted into a 50 ml Pyrex test tube, and the volume made up to 5 ml with extracting solution. 10 ml N ammonium acetate and 5 ml mixed reagent were added. Then, in quick succession, the following reagents were added, shaking after each addition —

1 ml 0.04% titan yellow

4 ml 10N NaOH

The/

The colour developed was measured in an E.E.L. colorimeter after 30 min using Ilford filter 624 (540 mμ), setting the instrument to zero with distilled water. The colour was compared with those produced from 5 ml aliquots of standard solutions treated in the same manner.

Interpretation of Results.

The results of the P, K and Mg determinations were expressed in mg/100 g air-dry soil. The scale for interpretation of the results for agricultural soils is given in Table 5.

Table 5. Scale for interpretation of soil analysis.

Soil status	"Available" nutrients (mg/100 g air-dry soil)		
	P	K	Mg
Low	< 0.3	< 6.5	< 5.0
Moderate	0.3 - 0.6	6.5 - 12.0	5.0 - 7.5
Satisfactory	> 0.6	> 12.0	> 7.5

Determination of Mineral N.

Mineral N was extracted from fresh soil samples within 2 - 3 hours of sampling. Soil moisture contents were determined at the same time, and the N was expressed in ppm of oven-dry soil. NH_4 was determined by measuring the yellow colour produced on Nesslerisation (100) and NO_3 by a slight modification of the brucine method of Robinson et al. (114), in which NO_2 was not destroyed, so that NO_3 results include any NO_2 that may have been present.

Determination of NH_4-N./

Determination of NH_4-N.

Extracts for determination of NH_4-N were obtained by shaking fresh soil with sodium acetate - acetic acid (pH 4.8) extracting solution (86), prepared by dissolving 200 g sodium acetate ($CH_3COONa.3H_2O$) in about 1 l. distilled water, adding 60 ml glacial acetic acid, and diluting to 2 l. when cool.

Fresh moist soil, equivalent to 25 g air-dry soil, was weighed into a 100 ml shaking bottle and 50 ml extracting solution were added. A 1 ml aliquot of activated carbon (0.4 g) was added to remove the yellow colour from the extract. After shaking for 30 min, the extract was filtered through a Whatman No.3 (15 cm) paper into a 100 ml conical flask.

Reagents:-

$(NH_4)_2SO_4$: range of standard solutions containing 0 - 10 ppm N, in extracting solution.

Nessler reagent: prepared by dissolving 45.5 g Hg_2I_4 and 35.0 g KI in water, adding 112 g KOH and diluting to 500 ml when cool. The reagent, which was stored in a dark bottle, was prepared a few days before use to allow any precipitate to settle out.

NaOH-tartrate solution: 40 g Na tartrate were dissolved in about 300 ml distilled water, 13 g NaOH added, and the solution diluted to 1500 ml.

5% Gum acacia: 10 g powdered gum acacia were dissolved in 195 ml distilled water and 5 ml Nessler reagent were added. This solution was prepared as required. It was allowed to stand for a few days before use to allow any precipitate to settle out.

Procedure:-/

Procedure:-

A 2 ml extract of sodium acetate - acetic acid extract was pipetted into a 50 ml Pyrex test tube, and the following reagents added in quick succession, mixing well after the last addition —

6 ml NaOH-tartrate

8 drops gum acacia

4 drops Nessler reagent

The colour developed was measured after 15 min in an E.E.L. colorimeter using filter OB10 (425 mμ) setting the instrument to zero with distilled water. A series of standards was prepared and analysed at the same time.

Determination of NO_3-N.

A sample of fresh moist soil equivalent to 25 g air-dry soil was extracted by shaking for 15 min with 50 ml $CaSO_4$ solution, prepared by diluting 250 ml saturated $CaSO_4$ solution to 2 l. with distilled water (115). The extract was filtered through a fluted Whatman No.42 (15 cm) paper, mixing the soil and extract just before addition to the filter paper — otherwise a clear filtrate was not obtained.

Reagents:-

KNO_3: range of standard solutions containing 0 - 5 ppm N, in extracting solution.

5% brucine in glacial acetic acid

conc H_2SO_4 (sp. gr. = 1.84)

Procedure:-

An aliquot of $CaSO_4$ extract was pipetted into a 50 ml Pyrex test tube and the volume made up to 3 ml with extracting solution. The following reagents/

reagents were then added in succession, mixing after each addition --

0.75 ml 5% brucine

6 ml conc H_2SO_4

The colour developed was measured after 15 min in an E.E.L. colorimeter using filter OB10 (425 mμ), setting the instrument to zero with a solution of chromic acid of sufficient concentration to bring the reading of the blank to just above zero. A series of standards was prepared and analysed at the same time.

Standardisation of Methods of Soil Analysis.

The methods used for the determination of pH, lime requirement, and "available" P, and K are those used in the Edinburgh School of Agriculture for routine soil analysis. They presented no problems.

The method used for the determination of "available" Mg in the soil was developed from the titan yellow method of Yien and Chesnin (162) for use with ammonium acetate - acetic acid soil extracts (24). In the determination of Mg in soils high in Ca, use of aliquots of soil extract greater than 1 ml sometimes resulted in precipitation of Ca. This sometimes occurred with 1 ml aliquots. As the precipitation was not instantaneous, results were obtained by measuring the colour after a shorter time interval than 30 min, before appearance of the precipitate. Because of day to day variations, a standard graph had to be prepared with each series of unknown determinations.

In the determination of mineral N in the soil, NH_4 was extracted by Na acetate - acetic acid. Such extracts are unsuitable for direct determination/

determination of NH_4 by Nesslerisation as they usually have a yellow or brown colour, but activated carbon added to the soil before extraction was satisfactory in producing almost colourless extracts. The carbon was tested before use by shaking 1 ml aliquots (0.4 g) for 30 min with 50 ml Na acetate - acetic acid extracting solution to which NH_4 standard solution had been added, filtering and determining the NH_4 content of the filtrate. The results, which are summarised in Table 6, show that the carbon released a small quantity of NH_4, but as the use of carbon did not affect the accuracy of the method, this problem was overcome by treating the standard NH_4 solutions with carbon in the same way as the soil extracts. (The full results are given in Appendix I, Table 22).

Table 6. Effect of carbon on the determination of NH_4 in the soil.

	Without carbon	With carbon
Mean NH_4 content (ppm N)	8.0	8.3
Standard deviation $\pm$	0.15	0.13
Coefficient of variation (%)	1.85	1.56

Difference between means (D) = 0.3

Standard error of the difference between the means (E) = 0.06

D/E = 4.36 $>$ t (P = .001)

An unexpected problem encountered during the standardisation of this method was the presence of considerable quantities of NH_4 in some acid-washed/

acid-washed analytical grade filter papers, possibly due to NH_4 absorbed from the atmosphere. The papers finally adopted for filtering soil extracts were Whatman No.3 from a freshly opened box, some papers from which were tested and found to be free from NH_4. Nevertheless, occasional high values sometimes occurred as a result of contaminated filter papers.

The accuracy of the methods of soil analysis was measured by analysing one sample 10 times for pH, "available" P, K and Mg, and mineral N. An estimate of the soil sampling error involved in the barley experiment was obtained by analysing once only 10 different samples of soil taken from the same area of 20 sq. yd. A summary of the results of these determinations is given in Table 7, and the full results are listed in Appendix I, Table 23.

Table 7./

Table 7. Standardisation of the methods of soil analysis.

Method		Mean	Standard deviation ±	Coefficient of variation (%)
pH	S	5.8	0.16	2.7
	A	6.0	0.07	1.1
		"Available" nutrients (mg/100 g soil)		
P	S	0.45	0.046	10.4
	A	0.36	0.121	5.8
K	S	10.9	1.31	12.0
	A	10.8	0.34	3.2
Mg	S	7.6	1.06	14.1
	A	7.3	0.30	4.0
		ppm N in oven-dry soil		
NO_3	S	3.5	1.10	31.0
	A	5.1	0.44	8.6
NH_4	S	3.6	1.29	36.1
	A	6.6	0.18	2.8

S = sampling error (includes analytical error)

A = analytical error

The analytical error in the determination of NO_3 was greater than is normally permissible, but on account of the large day to day variations that occur in the NO_3 content of soils (146) and because of the large errors involved in sampling, the method was accepted.

IV. RESULTS AND DISCUSSION.

All the results are tabulated in the Appendices, but only those having a direct bearing on the Mg nutrition of the plant are reported in the text. These results are presented mostly as graphs. Their statistical significance, as determined by analysis of variance (F-test), is shown by means of asterisks, and subscripts have been used to denote the linear, quadratic and cubic components of the treatment effects --

***	Significant, P = .001	$_l$	= linear
**	Significant, P = .01	$_q$	= quadratic
*	Significant, P = .05	$_c$	= cubic
N.S.	Not significant, P > .05	$_r$	= residual (quadratic + cubic)

Only those effects and interactions which occurred consistently or occasional effects that were highly significant are discussed in detail, although most other significant effects are mentioned. Occasional peculiar interactions occurred, usually at only one sampling in an experiment, showing no logical relationship to the obvious general pattern at the other samplings. These interactions, which may have reached significance solely by chance, were ignored.

The results have been presented and discussed separately for each experiment, and a brief general discussion follows in Section V.

1. BARLEY - FIELD EXPERIMENT (1962).

(Note: See pages 22 - 24 for details of the experimental design and fertiliser treatments.)

Mg Content.

Treatments had no significant effect on the Mg content of either grain or straw at harvest, but Fig. 1 shows that the Mg content of the plants at 4 earlier stages of growth was significantly increased by N.

$NaNO_3$ increased Mg content, but to a smaller extent than $(NH_4)_2SO_4$, especially at the 3-4 leaf stage, probably as a result of Na-Mg ion antagonism (26, 57), as the Na content of the barley was high throughout the season where $NaNO_3$ had been applied (Fig. 2).

Work with culture solutions, where the N was absorbed by the plant in the form in which it was added, has shown that the NO_3 ion exerts a beneficial effect on Mg absorption and that the NH_4 ion is antagonistic and inhibits the absorption of Mg (2, 154).

In this experiment, however, the antagonistic effect of NH_4 on Mg absorption was not observed following $(NH_4)_2SO_4$ application. Under the conditions of the experiment, NH_4 added to the soil and not taken up by plants and micro-organisms (or otherwise fixed), did not remain as NH_4 for long, presumably due to the action of nitrifying bacteria. This was shown by examination of the mineral N content of the soil several times during the growing season (Fig. 3). When the soil was first sampled on 14 May, 49 days after the fertiliser application, the mineral/

FIG. 1. Effect of $(NH_4)_2SO_4$ and $NaNO_3$ on the Mg content of barley, (1962).

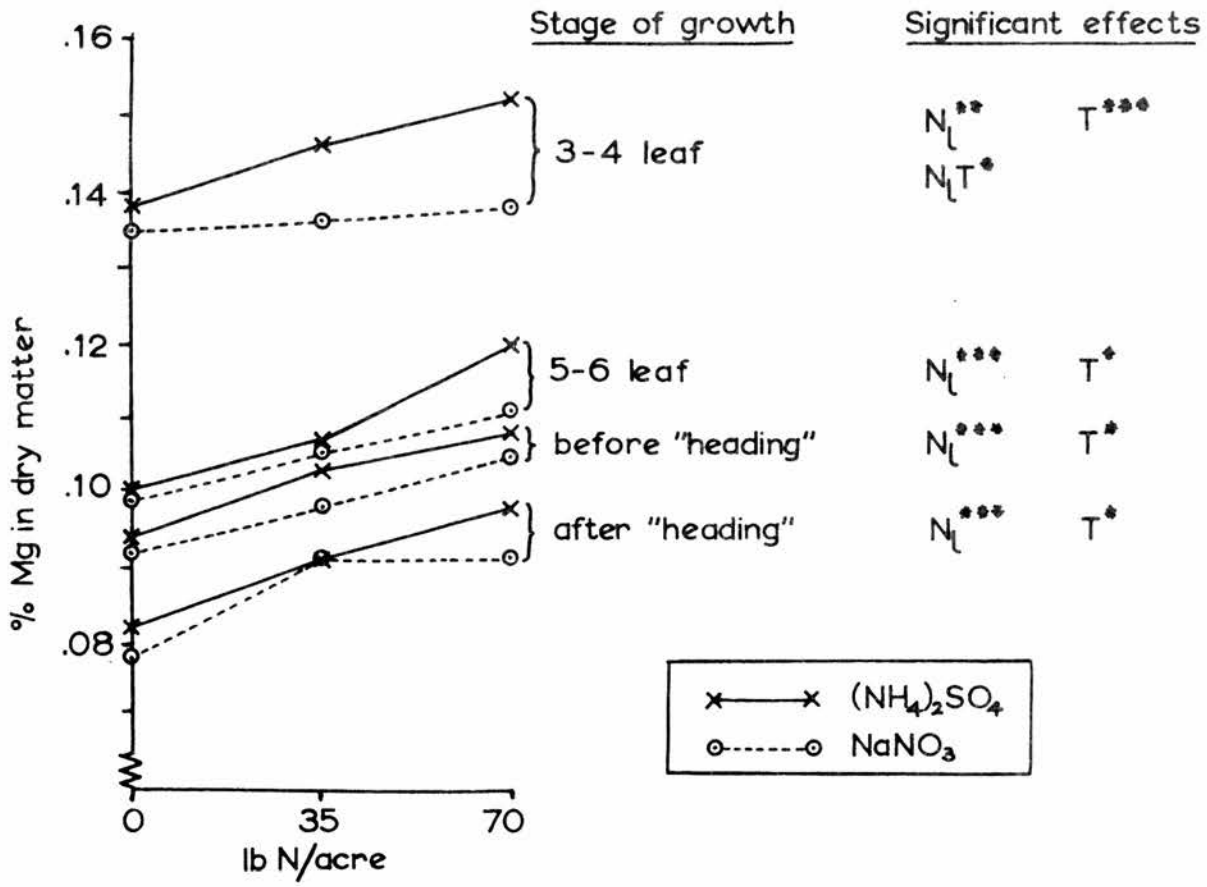


FIG. 2. Effect of $(NH_4)_2SO_4$ and $NaNO_3$ on the Na content of barley, (1962).

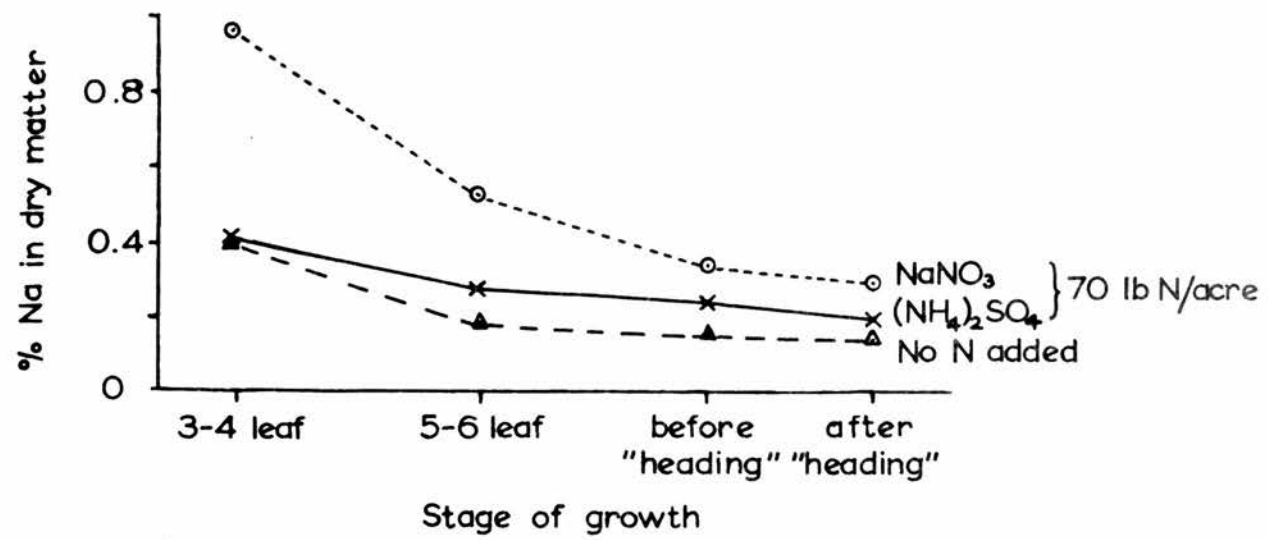
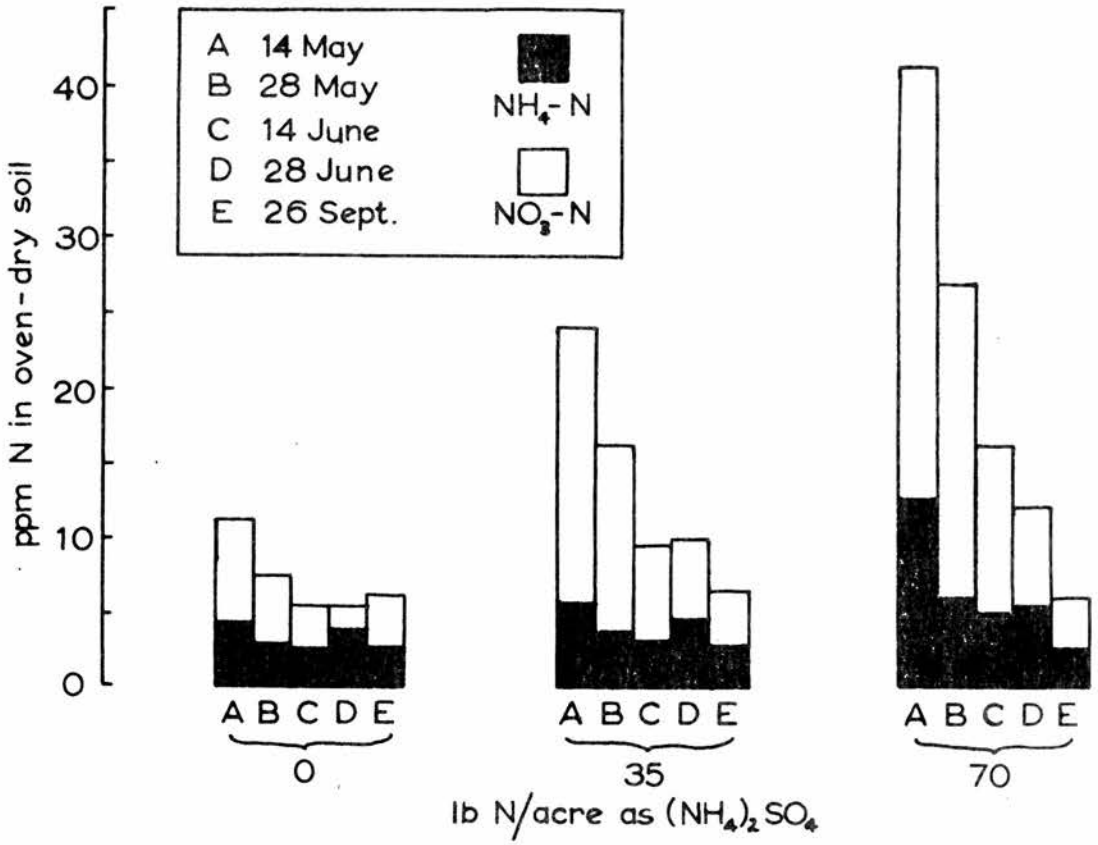
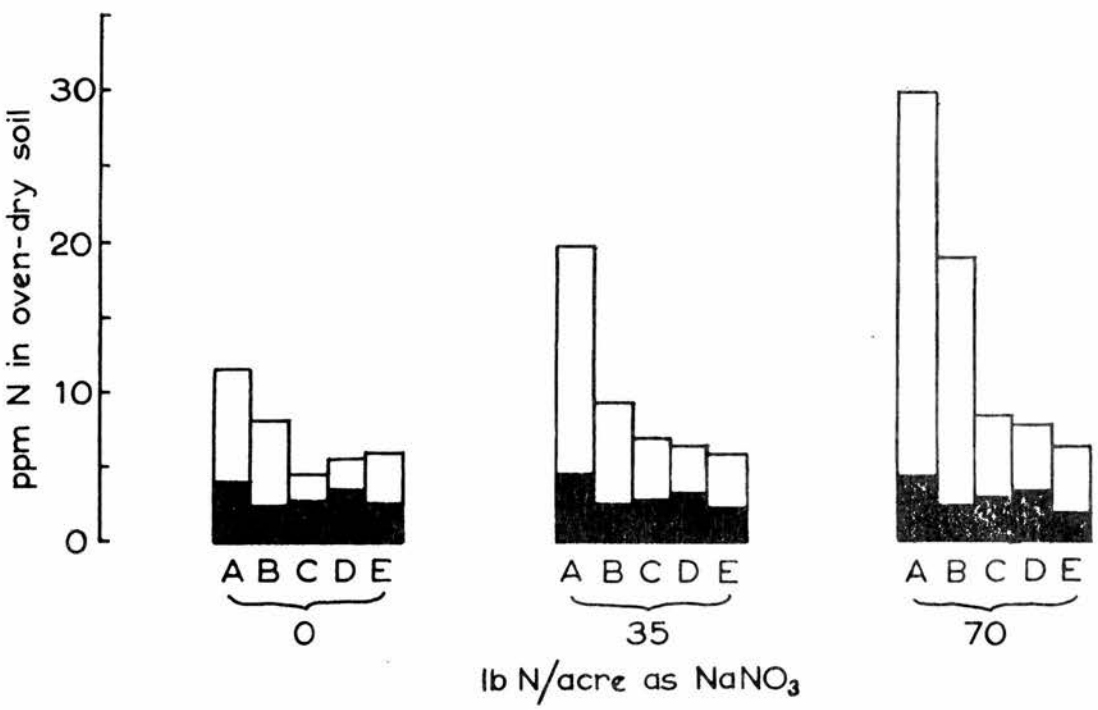


FIG. 3. Effect of $(NH_4)_2SO_4$ and $NaNO_3$ on soil mineral N content (barley expt.).





Note: 70 lb N/acre is equivalent to 35 ppm N in dry soil if one acre is taken as 2×10^6 lb dry soil.

mineral N in the $(NH_4)_2SO_4$-treated soil was predominantly in the form of NO_3. It is concluded, therefore, that the increased Mg content of the barley where $(NH_4)_2SO_4$ was applied, was an NO_3 effect following nitrification of the NH_4.

The levels of mineral N in the soil were unaffected by the limestone treatments. That there was no increase in mineral N content of the soil, arising from increased mineralisation of soil organic matter after liming, was probably due to greater crop uptake of N.

Although final yields were not determined because of harvesting difficulties, application of limestone visibly increased crop growth. An estimate of the effect of treatments on growth was obtained from visual observations taken on 22 June. The growth was estimated using a scale from 0 to 5, and the mean values for the N and limestone treatments are given in Fig. 4. $NaNO_3$ appeared to increase growth to a slightly greater extent than did $(NH_4)_2SO_4$, which would account for the higher mineral N content of the soil where $(NH_4)_2SO_4$ had been applied (Fig. 3).

Loss of NO_3 by leaching (which was an important factor in the 1962 pot experiment) probably did not occur to any great extent until the end of June, by which time the mineral N content of the soil had been reduced to a low level by plant uptake. Until then, the rainfall in the growing season was very light - a total of only 3.6 in. (Further weather data are given in Appendix II, Table 25.)

In studying the effects of NH_4 and NO_3 on Mg absorption, it is important/

FIG. 4. Effect of ground limestone, $(NH_4)_2SO_4$ and $NaNO_3$ on the growth of barley. An estimate from visual observations taken on 22 June 1962.

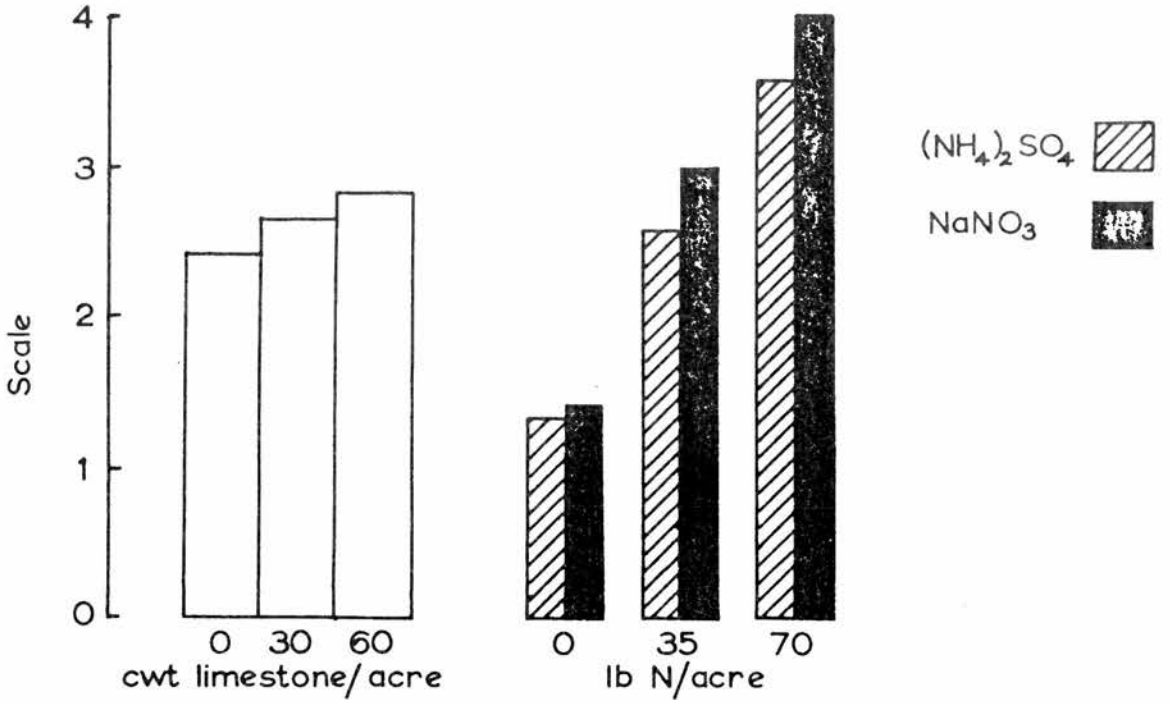
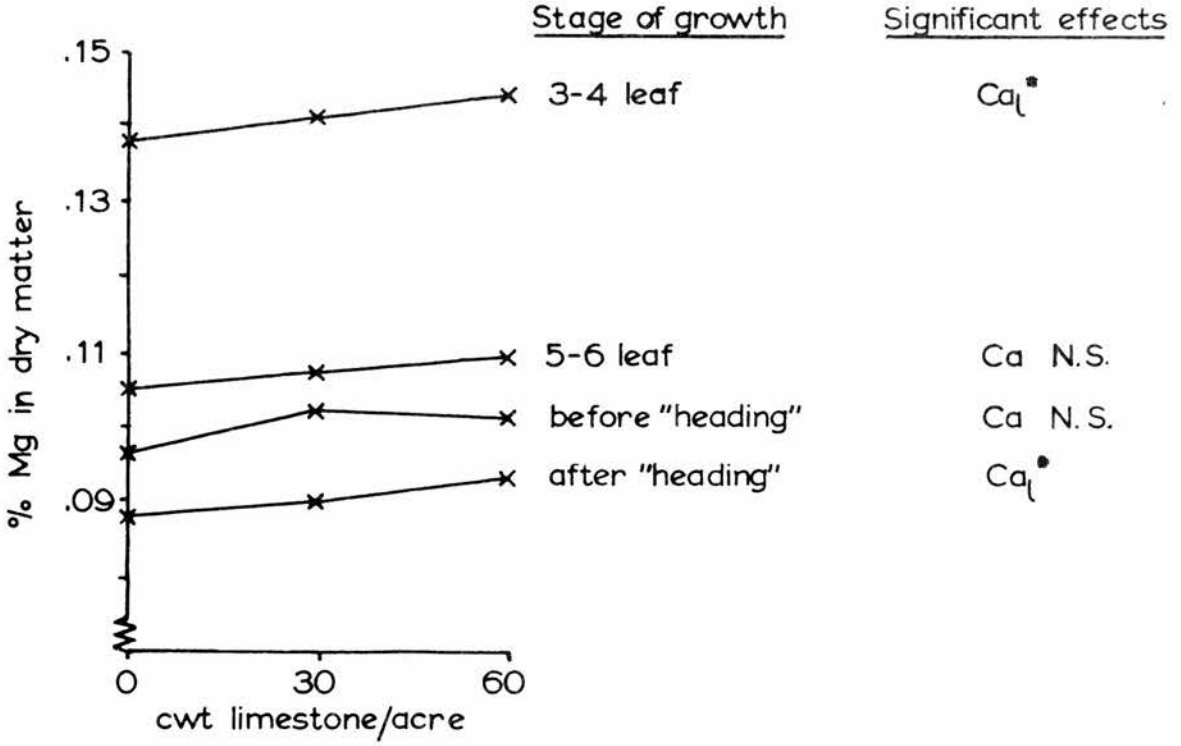


FIG. 5. Effect of ground limestone on the Mg content of barley, (1962).



important to consider the possible effects of the other ions added with the NH_4 and NO_3 ions, as shown by the results already presented. The beneficial effect of NO_3 on Mg content was small because of the strongly antagonistic effect of the added Na - much stronger than that of Ca.

Little work appears to have been done on the effect of Na on Mg absorption, but results of experiments by Dijkshoorn (26) and van Itallie (57) suggest that Na exerts almost as much influence as does K. Dijkshoorn grew perennial ryegrass in pots of sandy soil with N supplied in the form of nitrates. The increase in cation uptake resulting from application of KNO_3 or $NaNO_3$ was due almost entirely to the cation added, but, where $Ca(NO_3)_2$ or $Mg(NO_3)_2$ were applied, a considerable proportion of the increased cation uptake was due to K and Na. The ryegrass was apparently unable to absorb Ca and Mg sufficiently rapidly and as a result part of the increased cation uptake was due to cations not added in the fertiliser.

The results of the present series of experiments where N was applied as $NaNO_3$ or $Ca(NO_3)_2$ are in agreement with this work of Dijkshoorn, as shown in Table 8. The relative effects of different nitrates on Mg absorption depend largely on the antagonism of the cation added with the NO_3. The stronger the antagonism of the cation, the smaller is the increase in Mg content.

Table 8./

Table 8. Effect of $Ca(NO_3)_2$ and $NaNO_3$ on the cation content of oats and barley.

Cation content (%)	Barley (1962) 3-4 leaf stage			Oats (1962) 5-6 leaf stage			Oats (1963) 4-5 leaf stage	
	lb N/acre as $NaNO_3$			lb N/acre as $Ca(NO_3)_2$				
	0	35	70	0	40	80	0	90
K	2.81	2.56	2.61	2.77	3.09	3.23	2.80	3.44
Na	0.41	0.82	0.98	0.04	0.11	0.19	0.04	0.13
Ca	0.85	0.77	0.72	0.38	0.42	0.52	0.54	0.70
Mg	0.13	0.14	0.14	0.16	0.21	0.26	0.14	0.15

Application of ground limestone slightly increased the Mg content of the barley although the increase reached significance only at the 3-4 leaf stage (22 May) and after "heading" on 3 July (Fig. 5). The small content of Mg in the limestone (1.3% Mg) may possibly have contributed to the higher content of the barley. An application of 60 cwt ground limestone would add 87 lb Mg to the soil, but whether this amount would be of much value to the plant in the presence of the much greater quantity of added Ca (2218 lb) is doubtful. Despite the limestone having a lower Ca:Mg ratio than the soil, the limestone treatments increased the ratio of "available" Ca to Mg in the soil (Table 9). Many workers have shown that, although yield was not necessarily affected, increasing the ratio of "available" Ca to Mg in the soil decreased plant Mg content as a result/

result of increased Ca-Mg antagonism (36, 54, 61). No such decrease occurred in this experiment. Other factors, associated with liming and which exerted more influence on Mg absorption than Ca-Mg antagonism, must have been operating — e.g. addition of Mg to the soil; displacement of Mg from the base exchange complex; release of Mg from decomposing organic matter.

Table 9. Effect of ground limestone on the ratio of "available" Ca to Mg in the soil. (Barley experiment 1962).

Ground limestone cwt/acre	"Available" nutrients (mg/100 g soil)		Ca:Mg
	Ca	Mg	
0	152	5.6	16:1
30	207	6.0	21:1
60	247	6.0	25:1

The results in Table 9 were obtained from analysis of 3 soil samples bulked from those taken on 28 June for N determination. The Ca:Mg ratios quoted are equivalent ratios. The limestone contained 33% Ca, 1.3% Mg and had a Ca:Mg ratio of 15:1.

Application of limestone appeared to increase slightly the "available" Mg content of the soil at the end of the experiment, but the increase did not reach significance. Analysis of soil samples taken earlier in the season (Table 9) also showed a similar increase in Mg content following liming, so it is possible that limestone did increase the content of "available" Mg in the soil and that the method of sampling and analysis was not sensitive enough to measure the increase with sufficient accuracy for it to be significant.

There/

There was no significant difference between the mean content of "available" Mg before fertiliser application (6.6 mg Mg/100 g soil) and the mean content at the end of the experiment (5.8 mg Mg).

At the end of the experiment about 80% of the Mg added in the limestone was still present in the soil in a form which could not be extracted by ammonium acetate - acetic acid, but could be extracted by 0.5N HCl (Table 10). It was assumed that the HCl extracted all the added Mg left in the soil, and that the amount of soil Mg extracted was constant irrespective of the fertiliser and liming treatments. These results show that the Mg added in the limestone dissolved slowly in the soil.

Table 10. Mg extracted from the soil by 0.5N HCl (Barley experiment 1962).

Limestone	Added Mg	Mg extracted by 0.5N HCl (mg/100 g)		
cwt/acre	mg/100 g	Total	Soil Mg	Mg from limestone
0	0	21.0	21.0	0
30	2.2	22.8	21.0	1.8
60	4.4	24.8	21.0	3.8

The slow availability to plants of Mg added in limestones has been reported by many workers, including Jones (63), who found that application to the soil of 40 cwt/acre magnesian limestone (10% Mg) had little effect on herbage Mg content in the year of application and the maximum effect in increasing content did not occur until 4 years later.

Reith/

Reith (112) has reported similar results. Reith also found that application of ordinary calciferous limestone containing 1.2% Mg slightly increased the exchangeable Mg content of the soil compared with application of Buxton ground limestone containing only 0.1% Mg. These results showed that at least some of the Mg in the calciferous limestone had dissolved, but the Mg content of crops at harvest were the same after both treatments. In other experiments, Reith (110, 111) noted occasional slight increases in the Mg content of crops following application to acid soils of calciferous limestones containing up to 1.4% Mg.

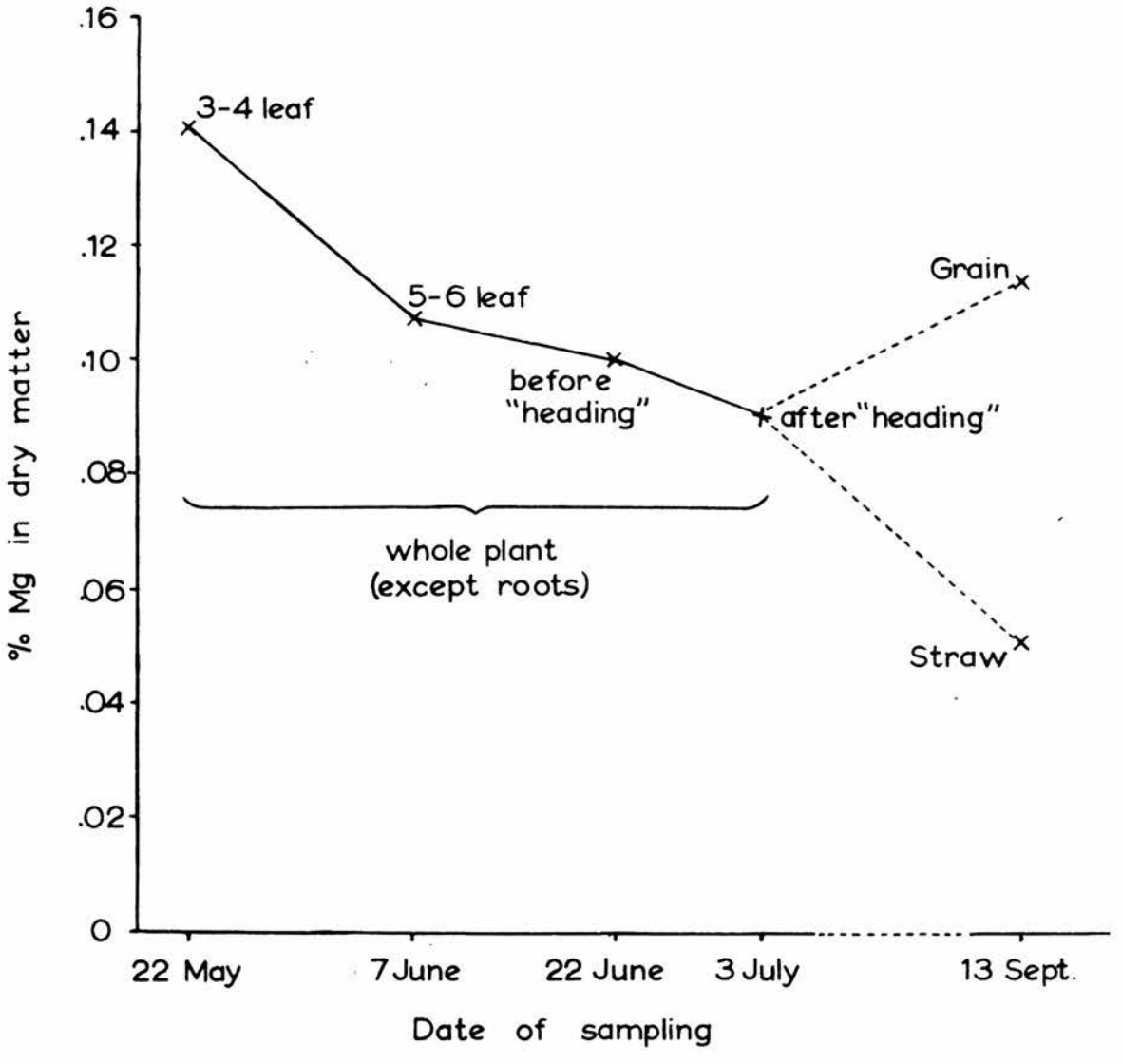
Increased Mg content of the barley, in this experiment, may have been partly due to mobilisation of Mg in the soil following application of the limestone, as increased Mg content of drainage water after liming has been reported by several workers, including Lyon and Bizzell (74) and Moser (88). The actual form that this mobilisation takes is not known for certain, but Mg displaced from the base exchange complex in the soil by added Ca would be made more liable to leaching losses and perhaps more available for plants.

The application of limestone increased soil pH —

cwt limestone/acre	0	30	60
Mean pH	5.6	5.9	6.0

This would make conditions more favourable for the organisms that break down organic matter in the soil. As a result there would be more/

FIG. 6. Effect of stage of growth on the Mg content of barley, (1962).



more rapid release of Mg from the organic matter. There would also be more rapid release of mineral N which may have contributed to the increased Mg content of the barley by stimulating Mg absorption.

It is concluded that the increased Mg content of the barley after liming was due to a combination of some or all of these factors mentioned above. It is unlikely that direct competition of H ions was of much importance on this soil, as the soil pH of 5.6 was above the pH levels reported in the literature, below which H ion competition reduces Mg absorption (4, 5, 84, 128, 152).

The effect of stage of growth on plant Mg content at the different treatments is shown in Figs. 1, 5, 6. As expected, the Mg content fell as the plants matured. When the barley was sampled at maturity (13 Sept.), there was no significant effect of treatments on the Mg content of either grain or straw, although treatments that increased yield would also increase total Mg uptake. The Mg content of the grain (0.11%) was more than double that of the straw (0.05%), a fact commonly reported in the literature (60).

2. OATS - POT EXPERIMENT (1962).

(Note: See pages 26 - 28 for details of the experimental design and fertiliser treatments.)

Yield of Dry Matter.

Application of either $(NH_4)_2SO_4$ or $Ca(NO_3)_2$ increased the yield of oats on both soils at all stages of growth (Fig. 7). The effects of/

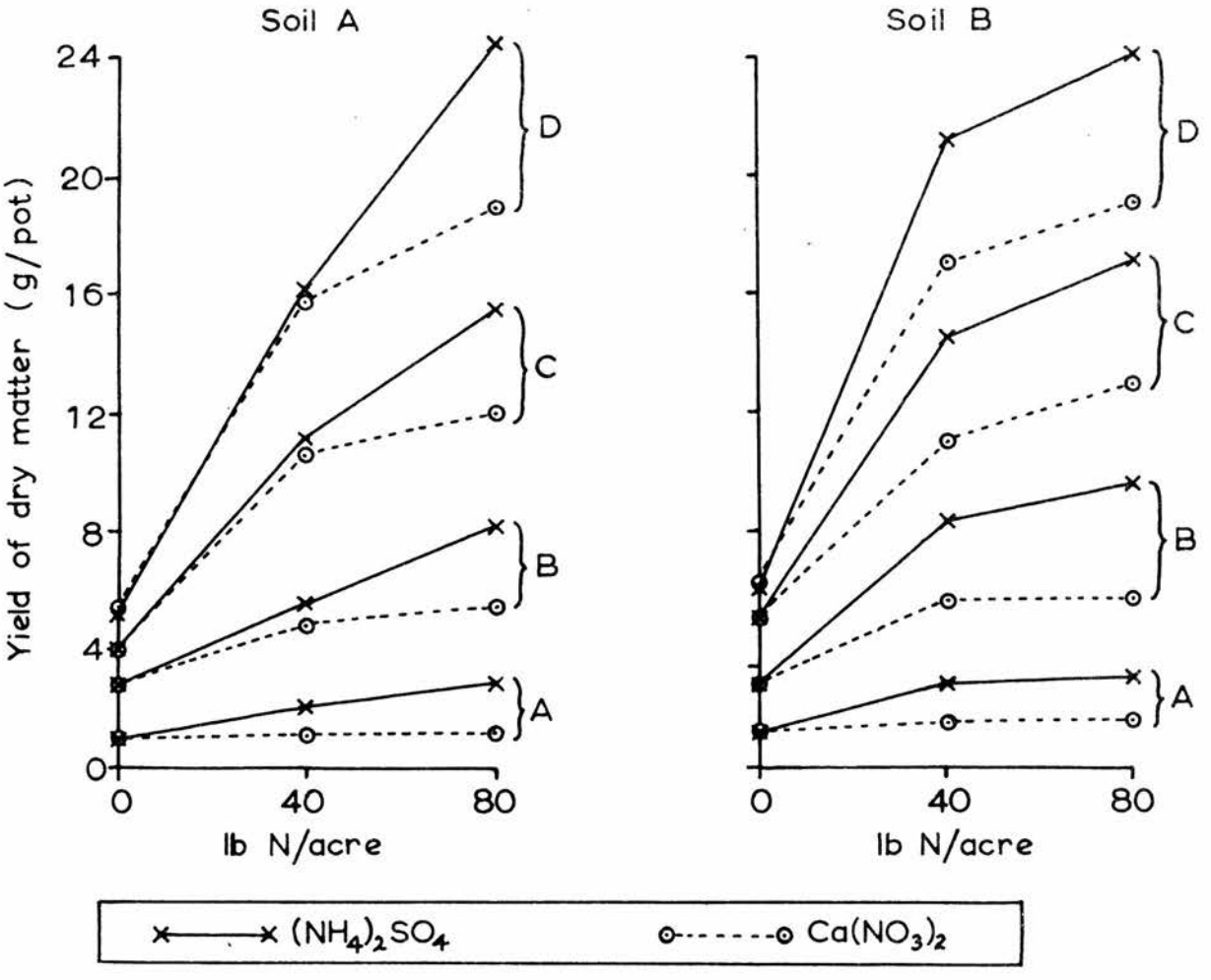
of N on the growth of oats after "heading" are illustrated in Plate 3. That $(NH_4)_2SO_4$ gave higher yields than $Ca(NO_3)_2$ was almost certainly due to loss of NO_3 by leaching. At the beginning of April, before the oats had emerged, the bare soil in the pots was subjected to a prolonged period of heavy rainfall - 0.8 in. fell on 2 April - and there was considerable drainage from the pots. (Details of the weather are given in Appendix III, Table 37).

The actual loss of NO_3 in the drainage water was not measured, but symptoms of N deficiency developed very rapidly about 20 - 24 May on plants in most pots. Most affected were plants which had received no N, but even plants which had received $Ca(NO_3)_2$ equivalent to 80 lb N/acre also showed symptoms of N deficiency. Only those plants which had received $(NH_4)_2SO_4$ equivalent to 80 lb N/acre appeared unaffected. At this stage (27 May) additional N was given at rates equal to the original applications.† Except where no N was applied, the oats recovered rapidly and symptoms disappeared. Plate 4 illustrates the poor growth and pale green colour of oats deficient in N.

It was obvious from the growth and appearance of the oats that leaching of N occurred not only where N was applied as $Ca(NO_3)_2$, but also/

† This means that oats sampled after 27 May received a total N application equivalent to 0, 80, 160 lb/acre but in order to avoid confusion, the levels of N referred to in the presentation and discussion of the results are the initial applications of 0, 40, 80 lb/acre.

FIG. 7. Effect of $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ on dry matter yield of oats, (1962).



Significant effects:-

A	B	C	D
3-4 leaf stage	5-6 leaf stage	before "heading"	after "heading"
N_l^{***} S^{***}	N_l^{***} S^{***}	N_l^{***} S^{***}	N_l^{***} S^{***}
- T^{***}	N_r^{***} T^{***}	N_r^{***} T^{***}	N_r^{***} T^{***}
TN_l^{***} ST^{***}	TN_l^{***} ST^{***}	TN_l^{***} ST^{**}	TN_l^{***} ST^{*}
TN_r^{*} SN_r^{**}	TN_r^{*} SN_r^{***}	- -	- SN_r^{***}

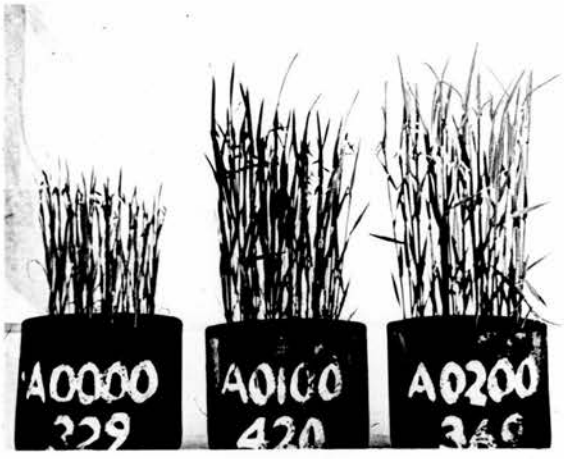
Plate 3. Effect of $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ on the growth of oats after "heading" (2 July 1962).

Soil A

0 40 80

lb N/acre as $(NH_4)_2SO_4$

Soil A



0 40 80

lb N/acre as $Ca(NO_3)_2$

Soil B

0 40 80

lb N/acre as $(NH_4)_2SO_4$

Soil B

0 40 80

lb N/acre as $Ca(NO_3)_2$

Plate 4. N deficiency in oats (Pot experiment, 1962).

Plate 5. Effect of soil on the growth of oats after "heading" (2 July 1962).

Soil B Soil A

40 lb N/acre as $(NH_4)_2SO_4$

Soil B Soil A

40 lb N/acre as $Ca(NO_3)_2$

also - although to a lesser extent - following $(NH_4)_2SO_4$ application. The NH_4 ion in soils is mostly adsorbed on the base exchange complex and not leached, although, as the rainfall in this experiment was at times heavy and persistent, some loss of NH_4 by leaching may have occurred. However, most of the N lost following $(NH_4)_2SO_4$ application was probably NO_3 formed on nitrification of the NH_4. As nitrification of all the added NH_4 would not take place immediately, there would be a high concentration of NH_4 in the soil for some time after the application and, as a result, leaching losses would be smaller than those following $Ca(NO_3)_2$ application.

The symptoms of N deficiency were more severe in plants growing on Soil A than in plants growing on Soil B, which suggests that leaching of NO_3 was greater from Soil A, or that the rate of mineralisation of organic N in Soil A was slower than in Soil B. Although mechanical analysis showed the texture of the soils - both derived from the same parent material - to be very similar (Table 11), Soil B, possibly because of its slightly higher organic matter content, had a better structure and water holding capacity. In dry weather Soil A dried out very rapidly, despite additional watering, and the surface tended to cap. These factors may have contributed to the consistently lower yields on this soil compared with Soil B (Plate 5).

Table 11./

Table 11. Mechanical analysis of the soils and coarse sand used in the 1962 oat experiment.† (Pipette method (105).)

(%)	Moisture	Loss on ignition	Gravel	Coarse sand	Fine sand	Silt	Clay
Soil A	2.0	8.7	-	22.8	35.7	17.5	14.2
Soil B	2.7	10.7	-	27.3	33.9	13.7	15.2
Coarse sand	0.8	0.3	11.9	82.4	4.1	1.0	0.9

† Before use in the experiment, the soils were mixed with an equal weight of the coarse sand.

Mg Content and Uptake.

Except at the 3-4 leaf stage on 18 May when Mg content was unaffected by either form of N, application of $Ca(NO_3)_2$ gave higher Mg contents than application of $(NH_4)_2SO_4$ (Fig. 8). The effects of applied N were similar on both soils, but oats grown on Soil A (11.7 mg "available" Mg/100 g soil) had consistently higher Mg contents than oats grown on Soil B (6.1 mg Mg) as shown in Fig. 9.

The absence of any noticeable antagonistic effect of NH_4 on Mg absorption may be attributed to nitrification of the NH_4, as in the barley experiment.

The beneficial effect of NO_3 on Mg absorption following the additional application of N on 27 May was very marked. The Mg content was greatly increased by both levels of $Ca(NO_3)_2$ at the 5-6 leaf stage on 11 June.

At later stages of growth, Mg content was decreased by both forms of/

FIG. 8. Effect of $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ on the Mg content of oats, (1962).

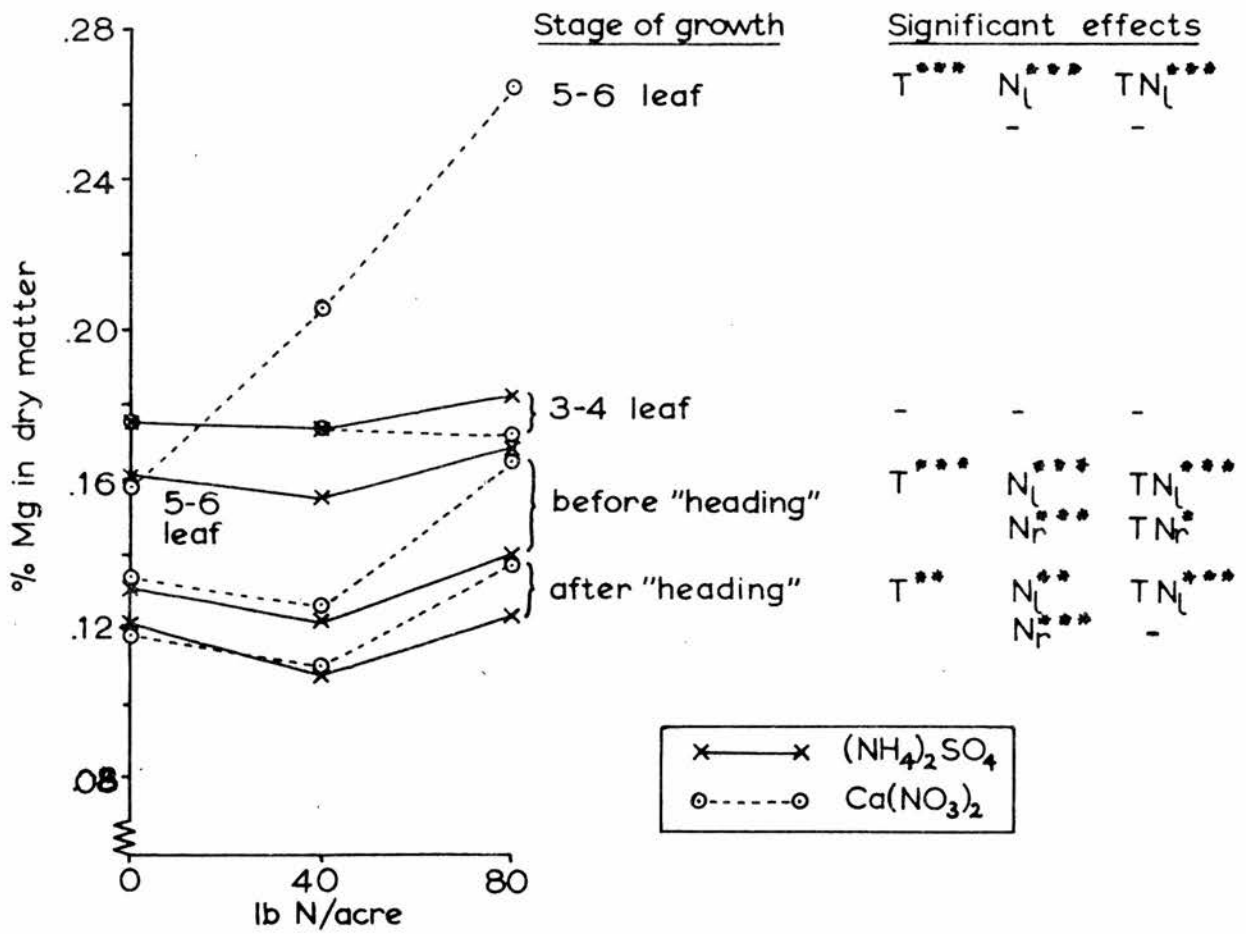


FIG. 9. Effect of Soil on the Mg content of oats, (1962).

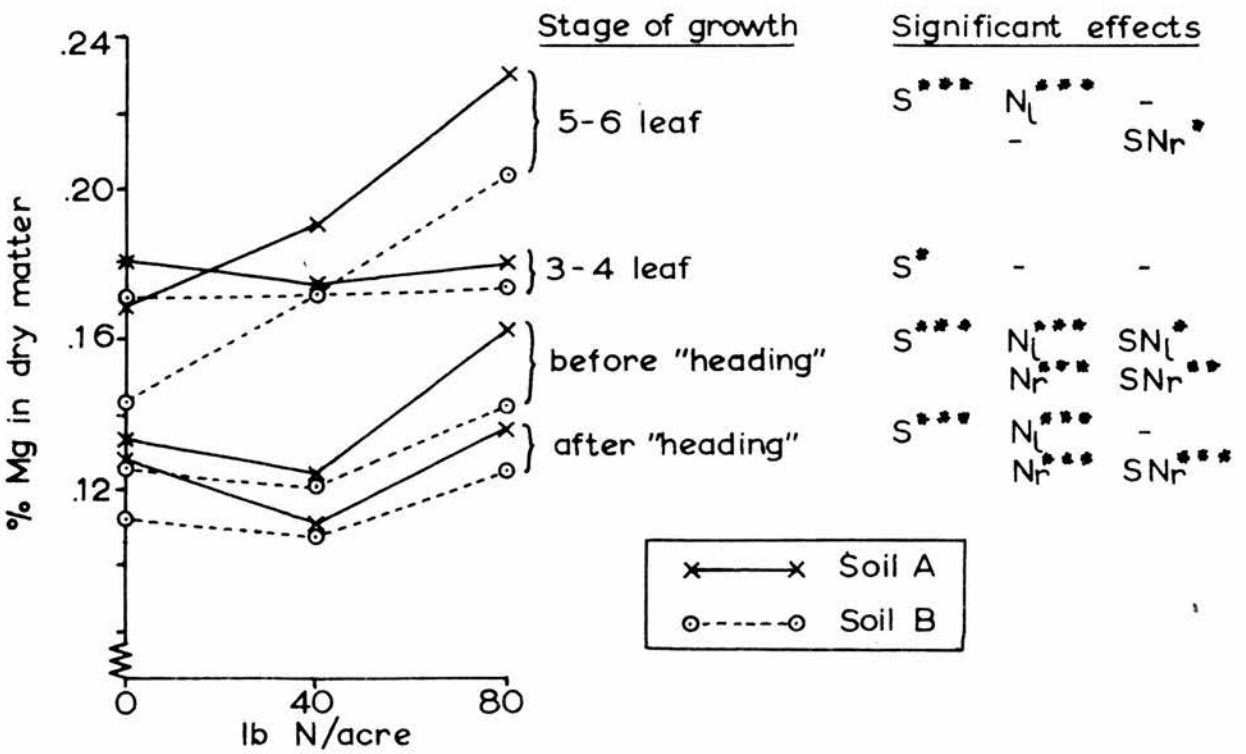
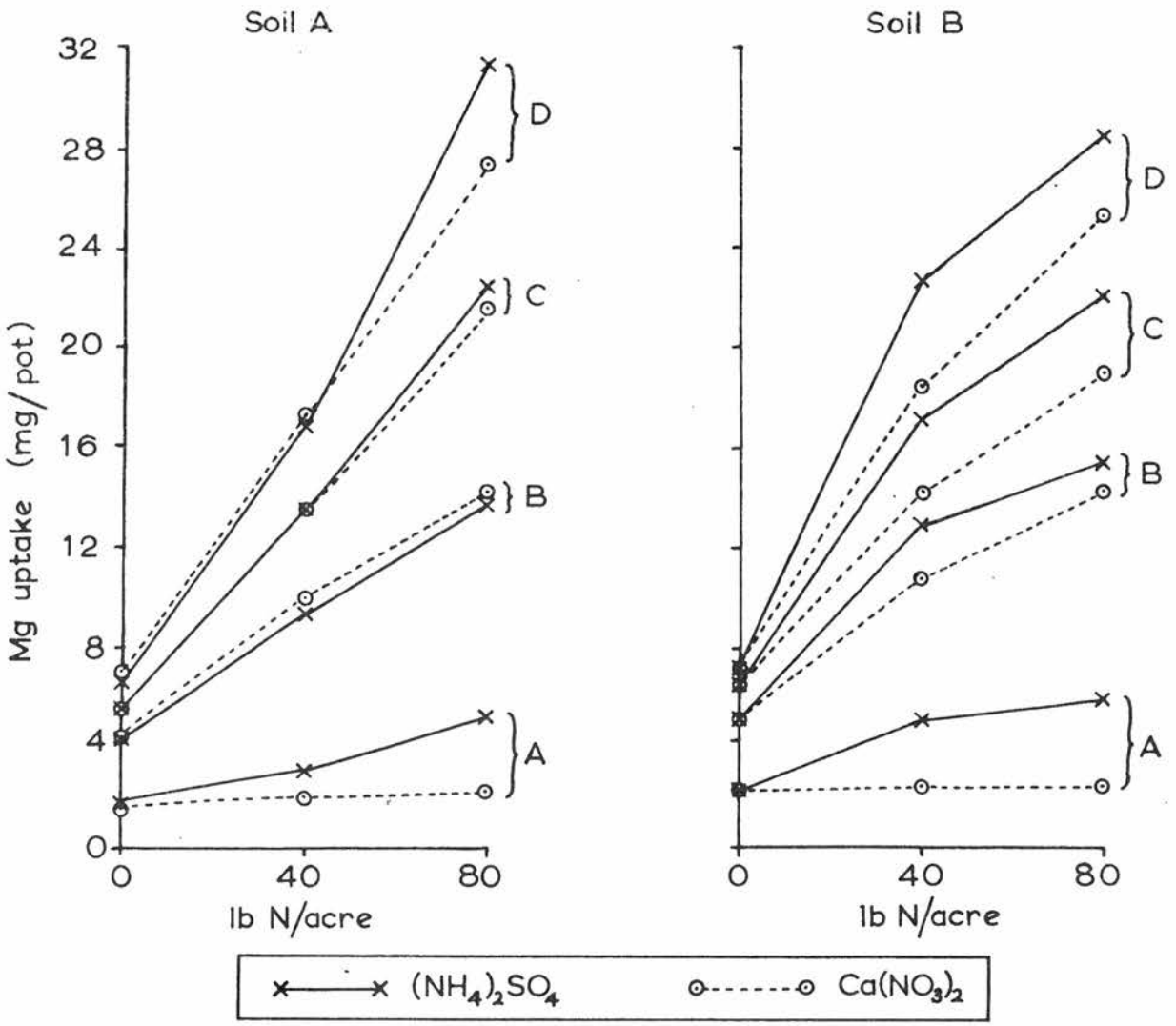


FIG. 10. Effect of $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ on the Mg uptake of oats, (1962).



Significant effects:-

A 3-4 leaf stage		B 5-6 leaf stage		C before "heading"		D after "heading"	
N_l^{***}	S^{***}	N_l^{***}	S^{***}	N_l^{***}	-	N_l^{***}	-
-	T^{***}	N_r^{**}	-	N_r^{*}	T^{***}	N_r^{*}	T^{***}
TN_l^{***}	-	-	-	TN_l^{**}	SN_l^{**}	TN_l^{***}	SN_l^{*}
-	SN_r^{*}	-	SN_r^{***}	-	SN_r^{**}	-	SN_r^{***}
ST^{*}		ST^{*}		ST^{**}		-	

of N applied at 40 lb/acre. The increase in Mg uptake, resulting from the application of N, was insufficient to keep pace with the rapid N-stimulated increase in growth. However, when N was applied at 80 lb/acre, the Mg content was increased. In this case, the increase in Mg uptake was proportionally greater than the increase in growth.

Because of its greater effect on yield, $(NH_4)_2SO_4$ increased total Mg uptake to a greater extent than did $Ca(NO_3)_2$, despite the higher Mg contents following $Ca(NO_3)_2$ application (Fig. 10). This was more noticeable on Soil B, where the superiority of $(NH_4)_2SO_4$ over $Ca(NO_3)_2$ in increasing yield was greater than on Soil A.

These results emphasise the importance of considering both the Mg content and total uptake of Mg by plants. A decrease in plant Mg content is not necessarily accompanied by a reduction in total Mg uptake if yield is increased at the same time.

Neither K nor Mg limited growth on either soil and their application to the soil had no effect on the yield of dry matter. However, K-Mg antagonism was observed in reduced content and total uptake of Mg by oats at all stages of growth following applications of KCl, which consistently increased K content and uptake (Figs. 11 - 14). K-Mg antagonism was not reflected in reduced yields because the soils had moderate to satisfactory "available" Mg contents. As Werner and Welte (157) have pointed out, it is only when the soil Mg content is below a certain "critical" level that the antagonistic effect of K applications/

applications in reducing Mg content may adversely affect yield and produce or aggravate symptoms of Mg deficiency. The actual "critical" level of soil Mg content below which yield is affected, depends to a large extent on the soil and climatic conditions and on the particular plant species being grown.

Application of $MgSO_4.7H_2O$ increased Mg content and total Mg uptake of oats at all stages of growth (Figs. 15, 16), but had no effect on the absorption of K.

These results of K and Mg applications illustrate the strong influence of K compared with Mg on the absorption of these ions by the plant, which has been previously reported by many workers, including Dijkshoorn (26), van Itallie (57) and York et al. (163).

Soils A and B had different contents of "available" Mg and K, but the effects of added Mg and K on plant Mg content and uptake were similar on both soils except on a few occasions, shown in Fig. 17. Although these effects did not occur consistently, they did indicate a tendency for added Mg to be more effective in increasing Mg absorption where the soil Mg content was low (Soil B). There were no significant K-Mg interactions.

Figs. 7 - 12, 15 and 16 show the effect of stage of growth on yield, Mg content and total uptake of Mg by oats with the different treatments. Mg content generally decreased as the plants matured, but stimulation of Mg absorption following the additional application of $Ca(NO_3)_2$ on 27 May, resulted in an increase in Mg content at the

5-6/

FIG. 11. Effect of KCl on the Mg content of oats, (1962).

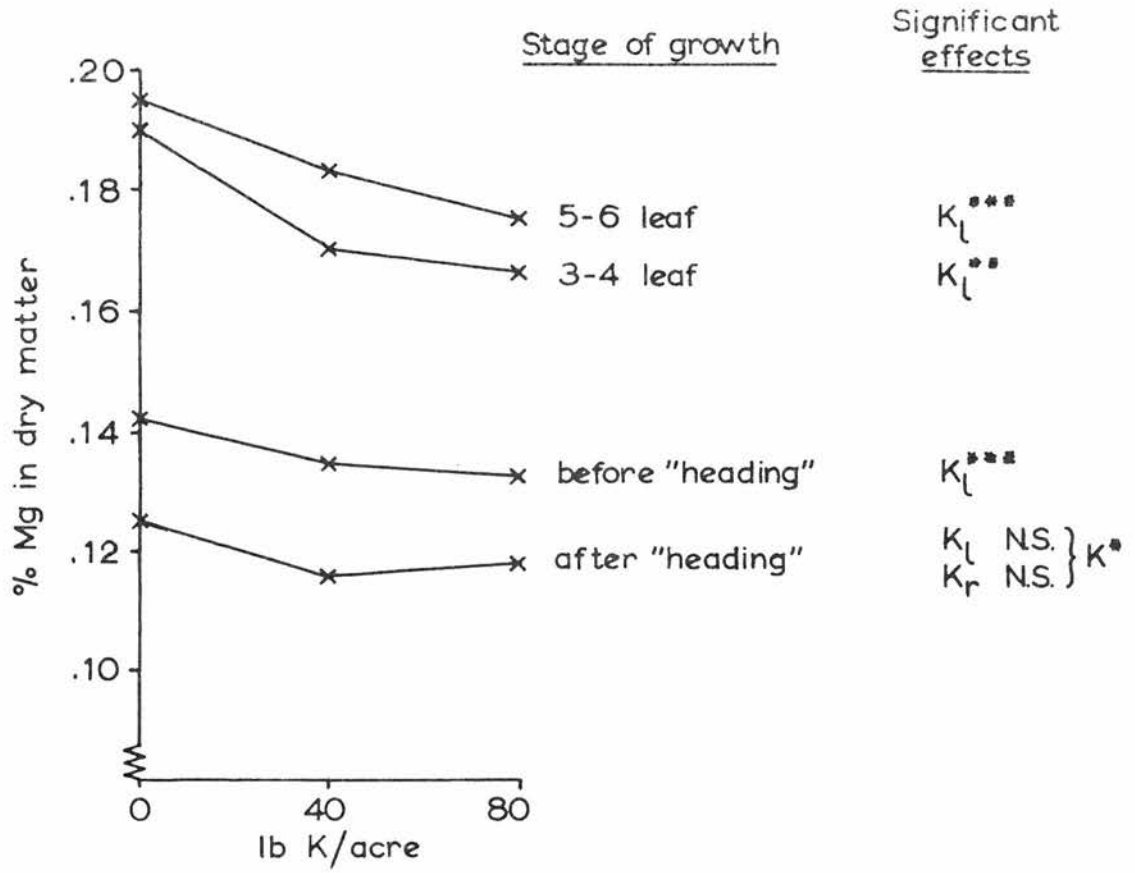


FIG. 12. Effect of KCl on the Mg uptake of oats, (1962).

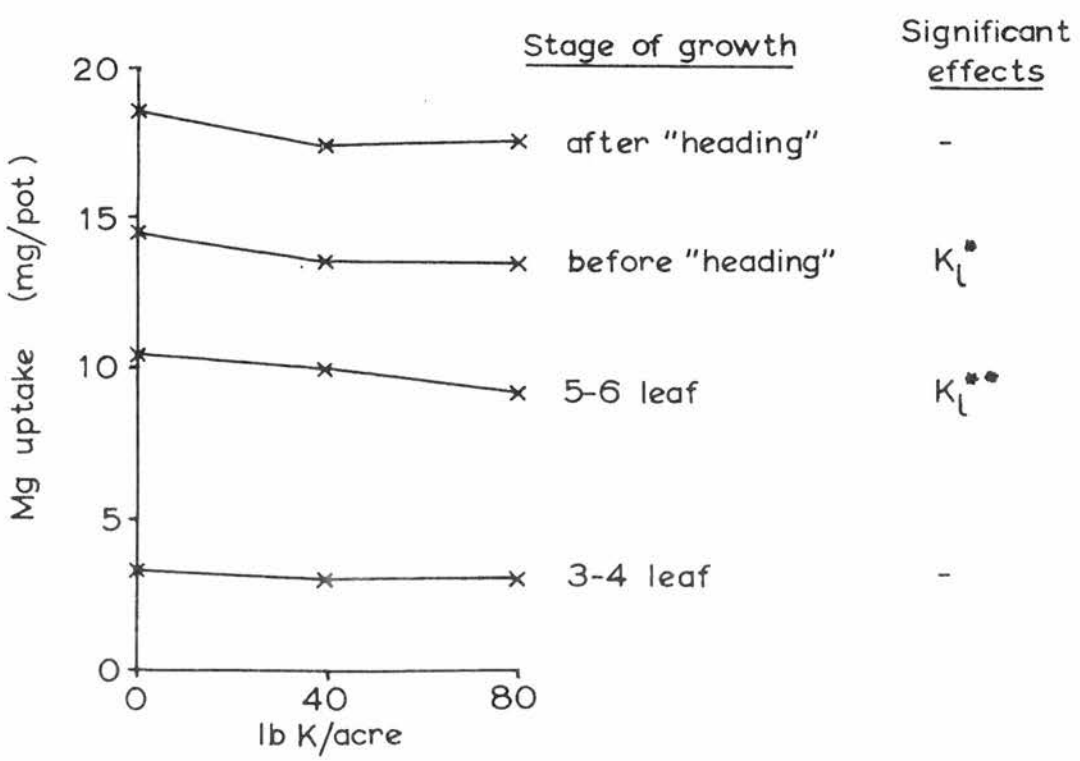


FIG. 13. Effect of KCl on the K content of oats, (1962).

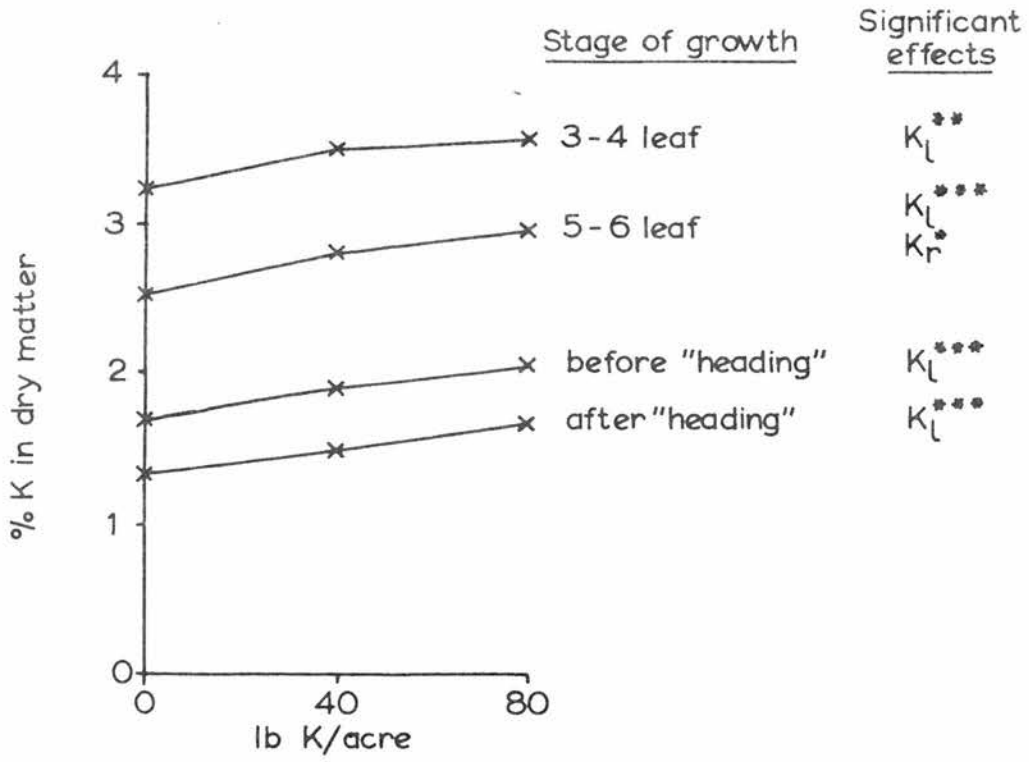


FIG. 14. Effect of KCl on the K uptake of oats, (1962).

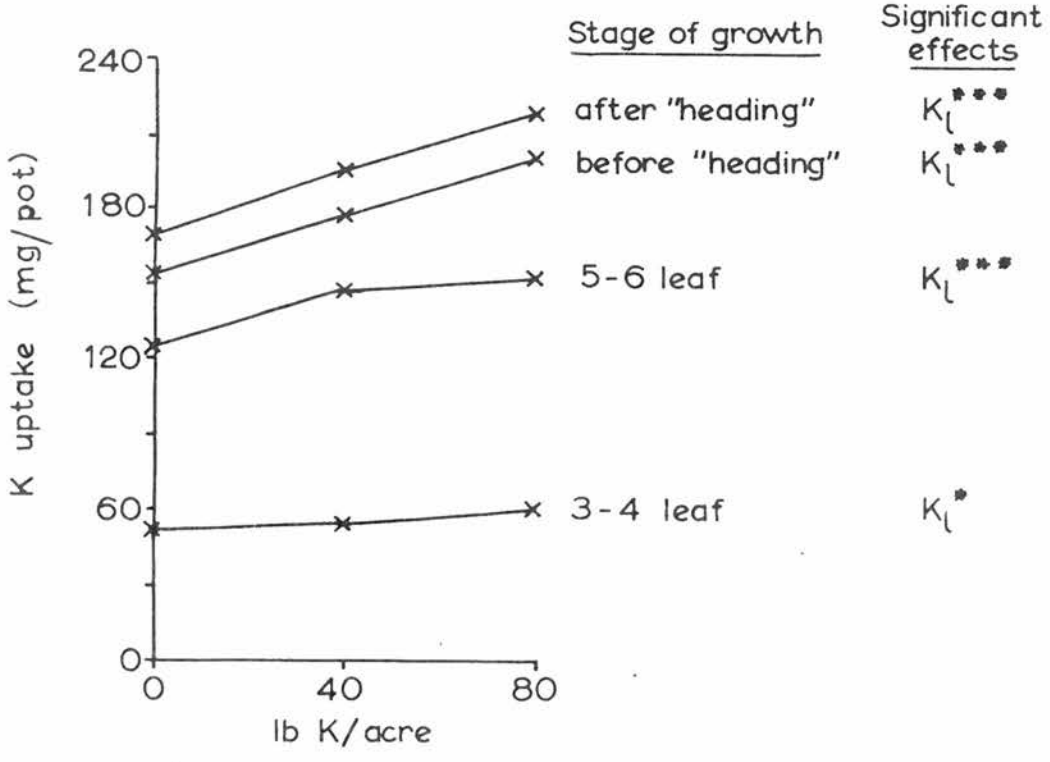


FIG. 15. Effect of $MgSO_4.7H_2O$ on the Mg content of oats, (1962).

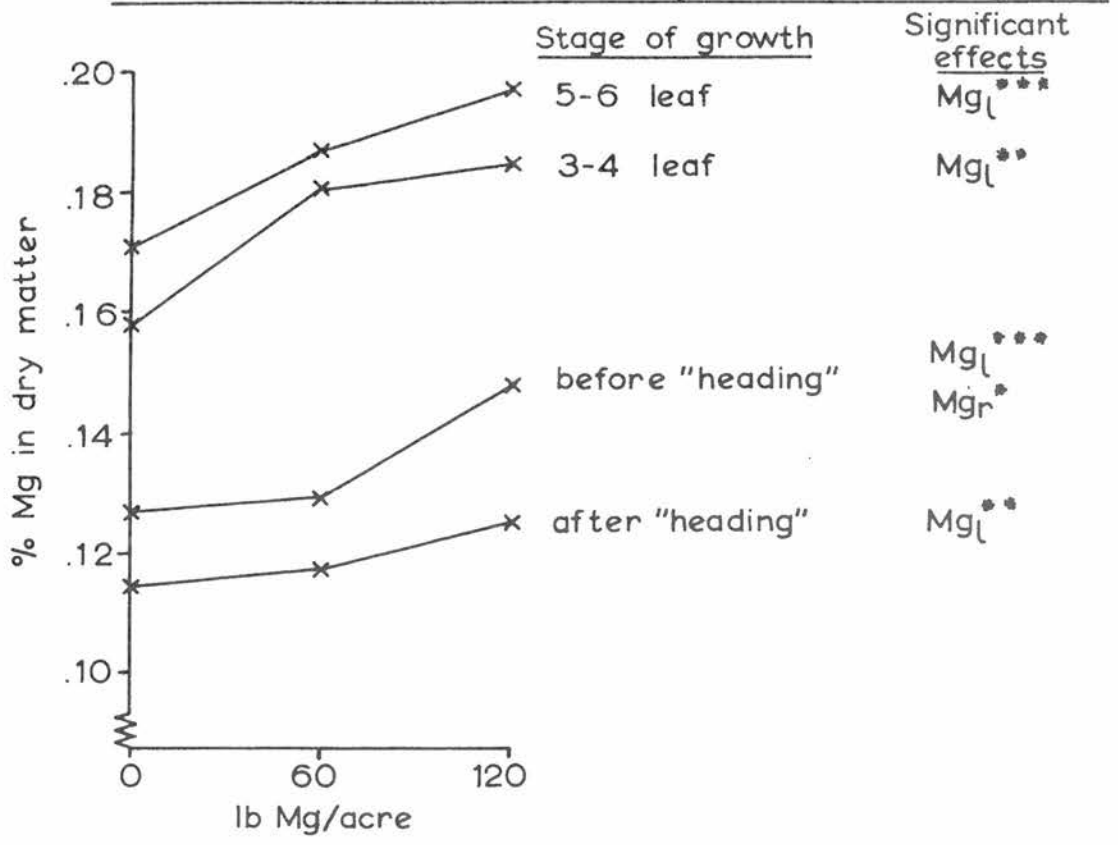


FIG. 16. Effect of $MgSO_4.7H_2O$ on the Mg uptake of oats, (1962).

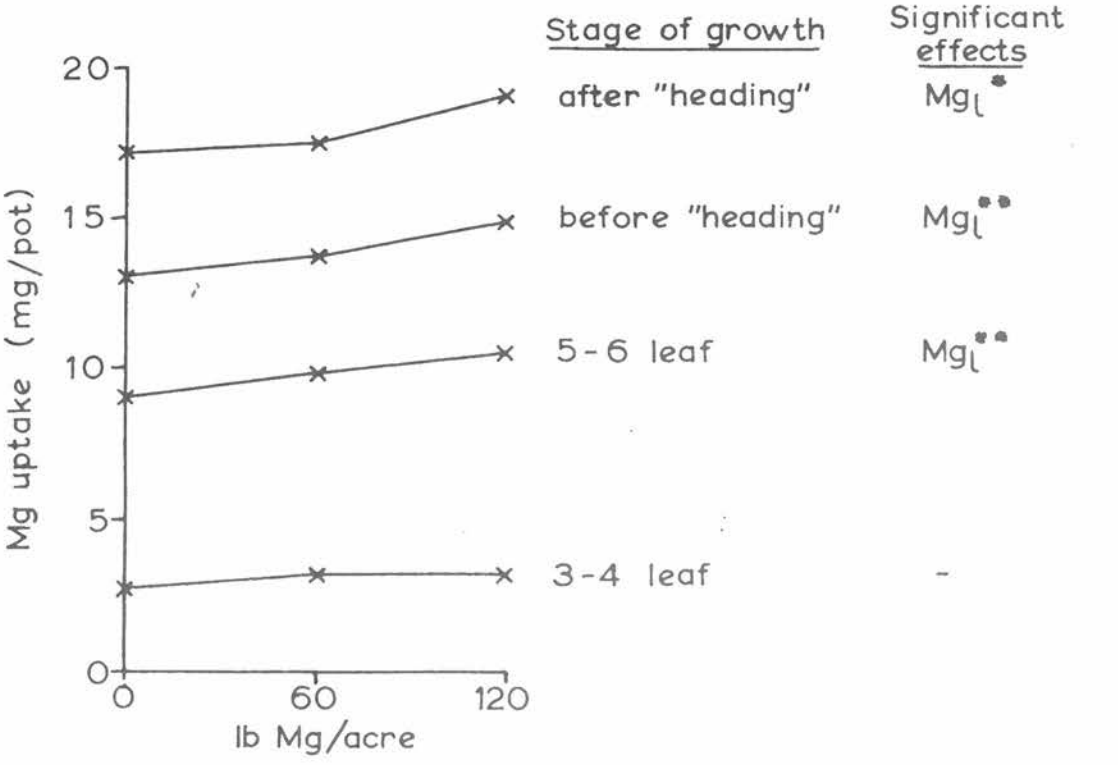
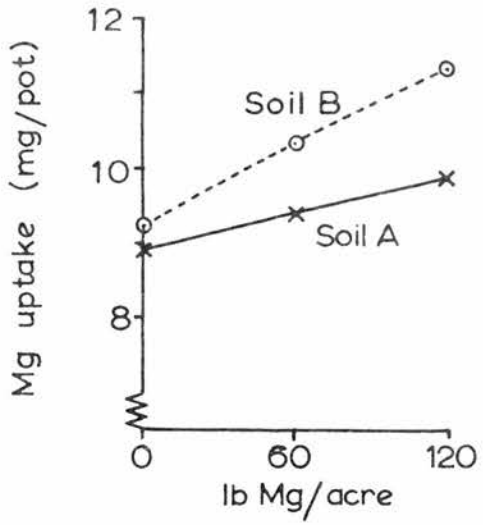
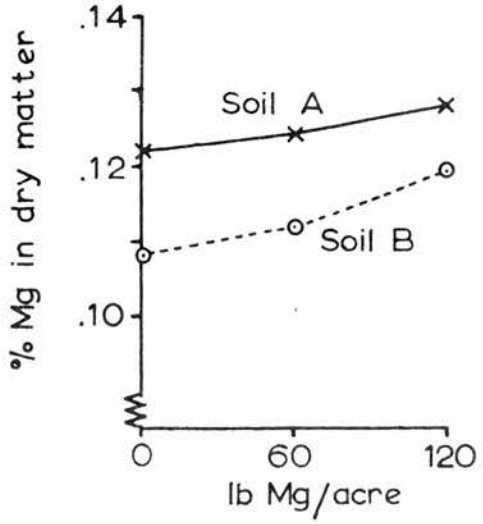


FIG. 17. Effects of KCl and $MgSO_4.7H_2O$ on the Mg content and uptake of oats, (1962): SMg and SK interactions.



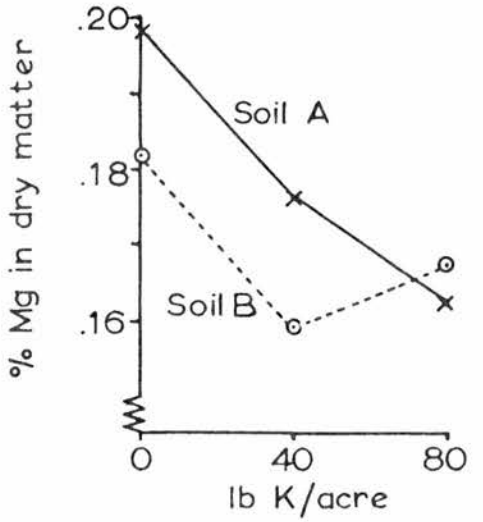
Mg uptake at the 5-6 leaf stage

SMg_l^*



Mg content after "heading"

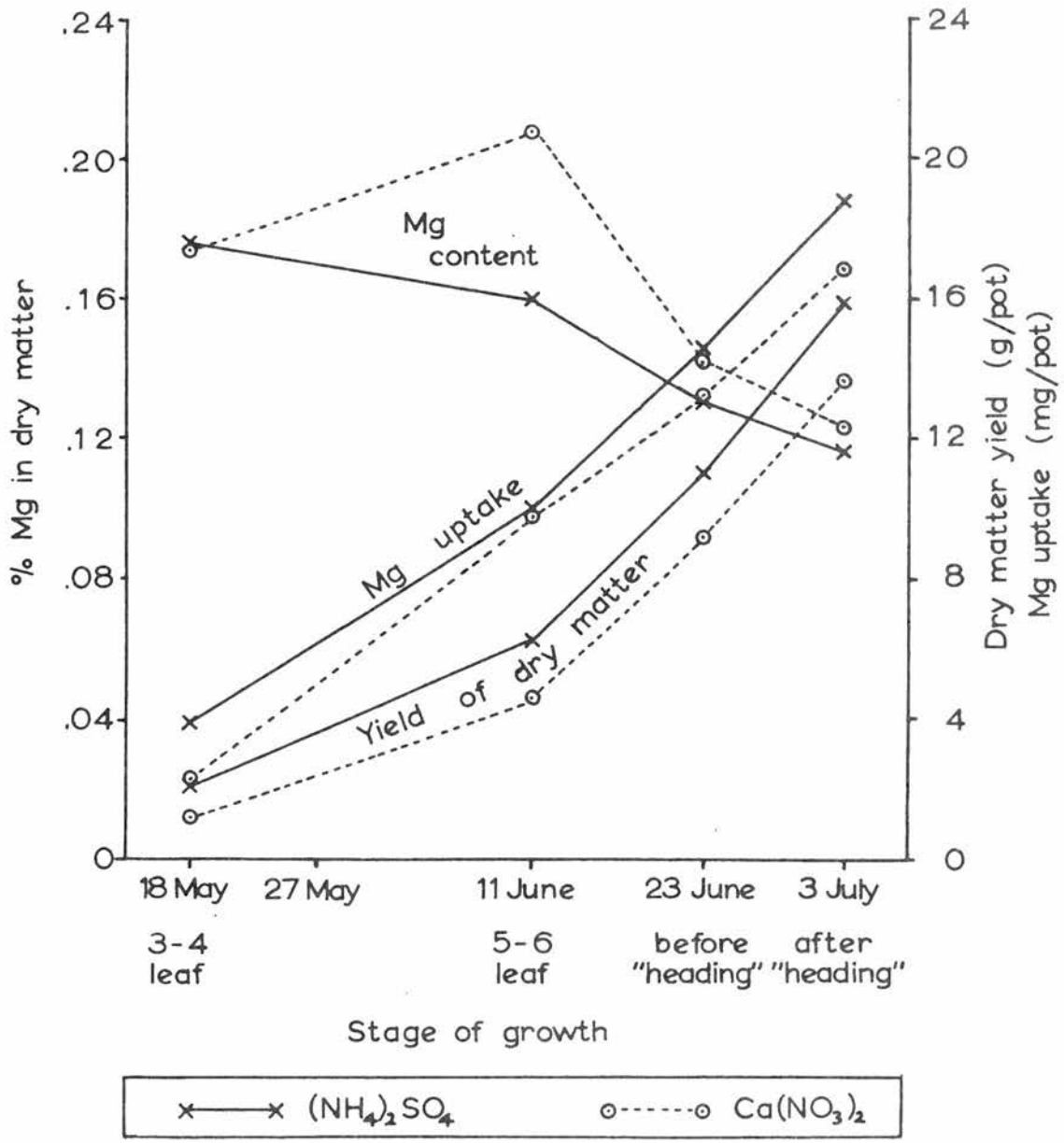
SMg_l^*



Mg content at the 3-4 leaf stage

SK_l^{**}

FIG. 18. Effect of stage of growth on Mg absorption by oats, (1962).



Note:- The additional N fertiliser application was given on 27 May.

5-6 leaf stage (Fig. 18). The effect of stage of growth on Mg absorption was similar on both soils.

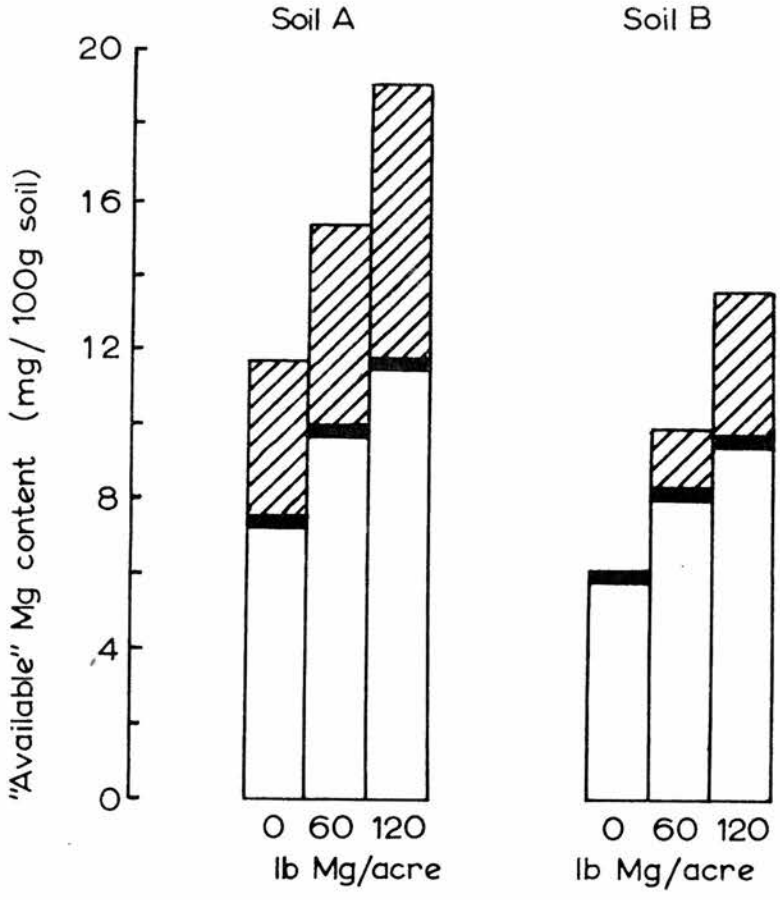
Soil Mg Content.

Application of KCl, which has been found by several workers to reduce the "available" Mg content of soils and to increase the loss of Mg in the drainage water (14, 49, 50), had no effect on the "available" Mg content of the soils in this experiment. Loss of Mg in the drainage water was not determined.

The effect of added Mg on the "available" Mg content of the soils at the end of the experiment is shown in Fig. 19.

The final "available" Mg content of Soil A was higher than that of Soil B, but the difference was not nearly so great as at the beginning of the experiment. Where no Mg was added, the initial and final Mg contents of Soil B were almost the same, and Mg application increased the "available" Mg in the soil. In Soil A, the Mg content, where no Mg was added, was reduced from 11.7 to 7.3 mg/100 g soil during the experiment and application of $MgSO_4.7H_2O$ at 120 lb Mg/acre was hardly sufficient to maintain the original content. The reasons for this difference are not clear, as the apparent loss of applied Mg was the same from both soils. Fig. 19 shows the total loss of "available" Mg from the soils -- i.e. the Mg not accounted for by plant uptake or present in the soil at the end of the experiment. (No account was taken of the Mg added in the oat seed or that present in/

FIG. 19. Effect of $MgSO_4.7H_2O$ on the content of "available" Mg in the soil, (Oat experiment 1962).



† Final Mg content

† Loss of "available" Mg

Reduction in soil Mg content due to plant uptake

} = Initial Mg content (soil Mg + added Mg)

† Significant effects:-

Mg_l^{***} S^{***}

Mg_r^{**}

in the roots. This amount of Mg would be very small compared with the total loss of "available" Mg, and neglecting it would not significantly affect the results.)

As Mg was not determined in the drainage water, it is not known whether all the loss of "available" Mg was due to leaching or if there was any fixation of Mg. Fixation may have occurred in Soil A. In Soil B, however, there must have been some release of Mg during the growing season as there was no loss of "available" Mg during the experiment where no $MgSO_4.7H_2O$ had been applied, and some leaching of Mg almost certainly occurred.

3. OATS - POT EXPERIMENT (1963).

(Note: See pages 31 - 32 for details of the experimental design and fertiliser treatments.)

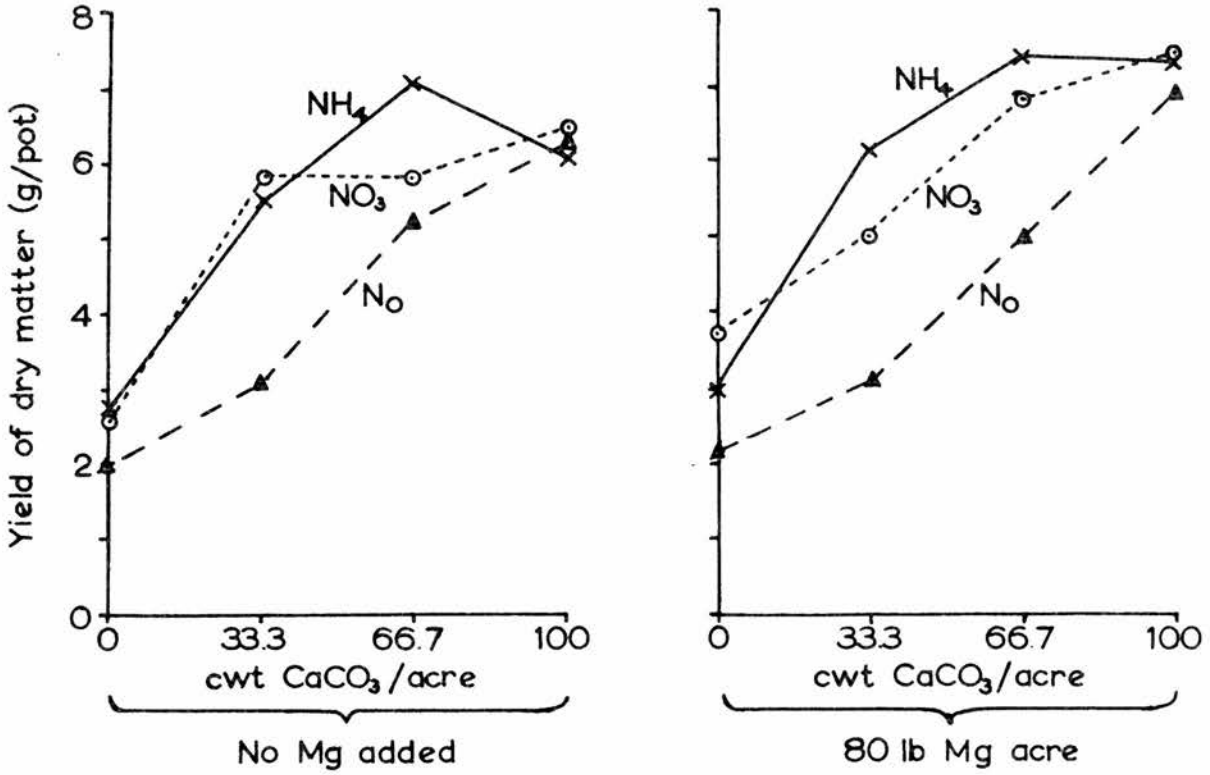
Yield of Dry Matter.

The effects of treatments on the yield of dry matter are given in Fig. 20. $CaCO_3$ was the most important single factor in increasing yield on this acid soil (Plate 6). $CaCO_3$ increased soil pH —

cwt $CaCO_3$/acre	0	33.3	66.7	100
Mean pH	4.6	5.8	6.6	7.1

— removed the adverse effects of soil acidity, and also supplied Ca. The soil was very low in "available" Ca (9 mg/100 g soil), and, although there were no symptoms specifically characteristic of Ca deficiency showing on oats growing on the unlimed soil, growth was poor and their Ca/

FIG.20. Effect of treatments on the dry matter yield of oats, (1963).



Significant effects:-

N_t^{***}	Ca_l^{***}	Mg^{***}	$Ca_l N_t^{***}$	$Ca_q Mg^{***}$
N_d^{**}	Ca_q^{***}		$Ca_q N_t^{***}$	
			$Ca_c N_t^{*}$	$Ca_c N_t Mg^{*}$
$N_t Mg^{*}$			$Ca_q N_d^{*}$	$Ca_c N_d Mg^{**}$

Note: In Figures 20-24, 27-29, and in Table 13 —

N_t = Overall effect of both forms of N

N_d = Difference in effect between $(NH_4)_2SO_4$ and $Ca(NO_3)_2$

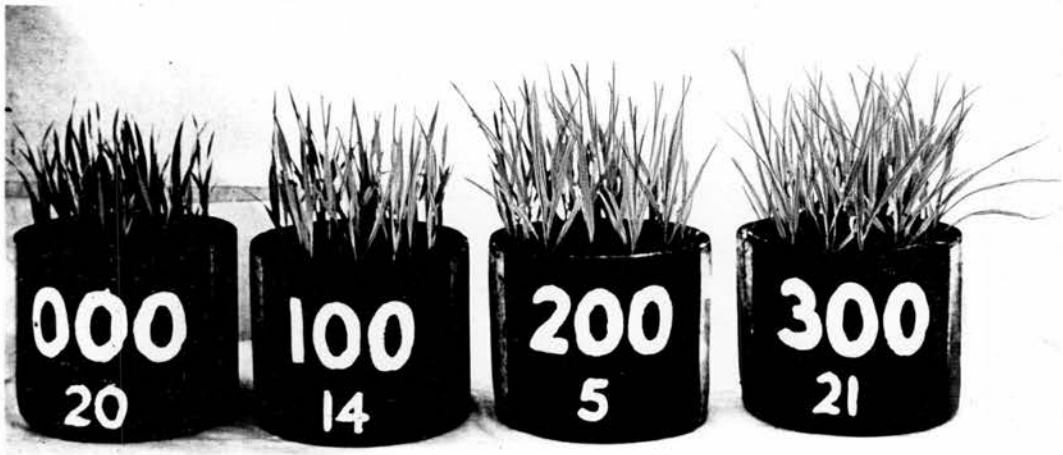
N_o No N added

NH_4 90 lb N/acre as $(NH_4)_2SO_4$

NO_3 90 lb N/acre as $Ca(NO_3)_2$

Plate 6. Effect of $CaCO_3$ on the growth of oats at the 4-5 leaf stage (3 June 1963).

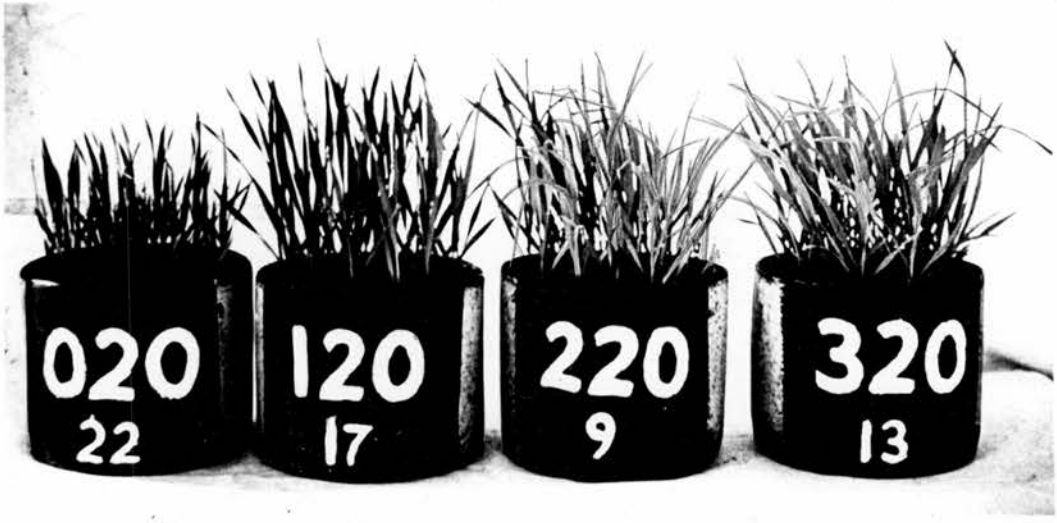
Without added N



0 33.3 66.7 100

cwt $CaCO_3$ / acre

With 90 lb N/acre as $Ca(NO_3)_2$



0 33.3 66.7 100

cwt $CaCO_3$ / acre

Ca contents were very low (0.13 - 0.47% Ca). Nicholas (96) reported 0.41% Ca as a deficiency level in young oats. The low yield of oats on the acid soil was probably partly caused by shortage of "available" Ca.

This conclusion was supported by the results of a small pot test carried out in the greenhouse with soil from the same source as that used in the main experiment. Application of 40 cwt $CaSO_4.2H_2O$/acre increased the yield of dry matter, Ca content, and total Ca uptake of oats (Table 12). As in the main experiment, the Ca content of oats growing on the untreated soil was a deficient level. The increase in yield on addition of $CaSO_4.2H_2O$ was obtained despite increased Ca-Mg antagonism on a Mg-deficient soil - reflected in lower content and total uptake of Mg, and despite a reduction in pH from 4.5 to 4.2, which greatly increased the amount of water-extractable Al in the soil, and may have caused or increased Al toxicity in the oats. Magistad (78) reported that levels of Al which caused toxicity in plants were in the order of 0.5 - 3.0 ppm and upwards in the soil solution, and this range is in agreement with work by other investigators (104, 120). Oats are relatively tolerant to Al, and although growth is adversely affected, they can withstand concentrations of Al sufficient to kill sensitive crops such as barley (46, 78).

Table 12./

Table 12. Greenhouse pot-test results (1963): effect of $CaSO_4.2H_2O$ and $CaCO_3$ on the growth and composition of oats at the 4 leaf stage.

Plant Analysis

Treatment	Dry matter yield (g/pot)	Mg uptake (mg/pot)	% in dry matter		ppm in dry matter	
			Mg	Ca	Mn	Fe
Control	2.17	2.58	.119	0.25	207	68
$CaSO_4.2H_2O$ 40 cwt/acre	2.42	2.37	.098†	1.00	160	76
$CaCO_3$ 100 cwt/acre	2.88	5.44	.189	1.28	71	94

Soil Analysis

Treatment	pH	"Available" nutrients (mg/100 g soil)			Al (ppm) water ‡ soluble	Al (ppm) in soil ǂ solution
		Ca	Mg	Mn		
Control	4.5	13	1.6	.26	0.8	1.9
$CaSO_4.2H_2O$ 40 cwt/acre	4.2	66	1.4	.31	10.6	24.8
$CaCO_3$ 100 cwt/acre	7.3	226	1.5	.11	0.3	0.6

† Mg deficiency symptoms - score 9.
‡ 25 g air-dry soil shaken for 30 min with 50 ml distilled water.
ǂ Estimated content.

If it is assumed that the amount of Al extracted from the soil by water is roughly equivalent to that normally present in the soil solution, then it is possible to estimate the concentration of Al in the soil solution. This has been done for the soils at total water holding capacity (30% moisture), and the results given in Table 12 show that inhibition of growth resulting from the presence of soluble Al may possibly have occurred in oats growing on the control soil (no treatment), and almost certainly occurred where $CaSO_4.2H_2O$ had been applied. Mn toxicity, which often accompanies Al toxicity in acid soils, did not occur. In fact, the exchangeable Mn content of the soil was low under all treatments, and where $CaCO_3$ was applied the Mn status of the soil was very low. Despite this, the Mn content of the oats (71 ppm) was well above the levels associated with Mn deficiency. Nicholas (96) quoted 66 ppm Mn as healthy and 9 ppm Mn as deficient levels in young oats, and Smith (176) reported 20 ppm Mn in leaves of young oats as the limiting level below which Mn deficiency may occur.

Although the conditions under which the pot-test was carried out were considerably different from those of the main experiment and the oats were harvested at a slightly earlier stage of growth (4 leaf as opposed to 4-5 leaf stage), the pot-test results indicate that the poor growth of oats on the unlimed soil in the main experiment was unlikely to be a result of Mn toxicity, but Al toxicity and Ca deficiency were probably involved. Apart from the direct toxic effect of high concentrations of soluble Al in the soil, Al may also cause P deficiency by/

by precipitating P either in the soil or in the plant (46, 104, 120). As P was not included as one of the treatments and added only as a basal dressing (20 lb P/acre), it is not known whether lack of P was limiting growth or not, but the P contents of oats growing on the unlimed soil (generally $<0.2\%$ P) were low for oats at this stage of growth (33).

The pot-test results also indicate that, although the exchangeable Mn content of the soil was very low, it is unlikely that shortage of Mn caused the falling off in yield increase at the highest rate of $CaCO_3$ application (Fig. 20). This effect may have been due to increased Ca-Mg antagonism, as the levelling out of the yield curve was more noticeable where no Mg was added.

The soil was deficient in "available" Mg (1.6 mg/100 g soil) and application of $MgSO_4.7H_2O$ increased the dry matter yield of oats, particularly at the highest rate of $CaCO_3$ application, where added Mg would reduce the adverse effects of excess Ca on Mg absorption, and on the unlimed soil where growth and root development were poor (Plate 7). The increase in yield on addition of $MgSO_4.7H_2O$ was not so great where $CaCO_3$ was applied at 33.3 and 66.7 cwt/acre, possibly because the improved soil conditions following liming enabled the plant to obtain Mg more readily than from the unlimed soil as a result of improved root development.

Application of either form of N increased yield. The effects of N on growth at different rates of $CaCO_3$ application are illustrated in Plate 8.

In/

Plate 7. Effect of $MgSO_4.7H_2O$ on the growth of oats at the 4-5 leaf stage (3 June 1963).

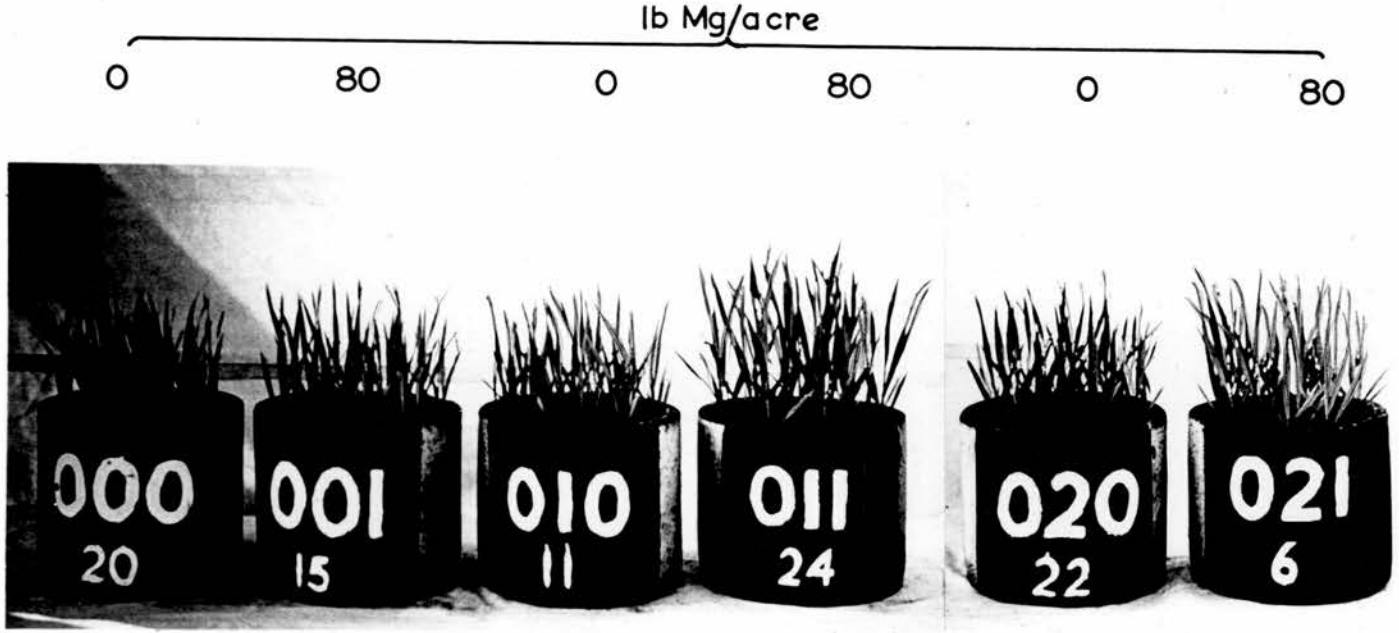
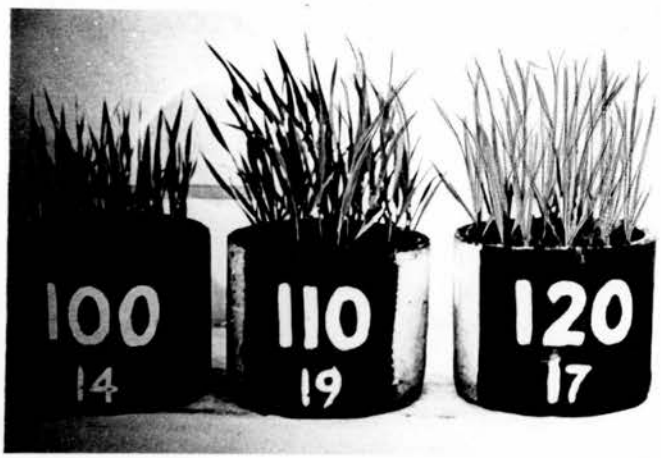


Plate 8. Effect of $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ on the growth of oats at the 4-5 leaf stage (3 June 1963).

No $CaCO_3$ added



33.3 cwt $CaCO_3$/acre

100 cwt $CaCO_3$/acre

No N added | $(NH_4)_2SO_4$ | $Ca(NO_3)_2$

90 lb N/acre

In the previous pot experiment in 1962, higher yields following addition of $(NH_4)_2SO_4$ compared with $Ca(NO_3)_2$ were attributed to loss of NO_3 by leaching. In order to reduce the chances of similar large leaching losses occurring in this experiment, the N was given in 3 applications during the growing season (which extended to only 8 weeks after the oats were sown). The rainfall in the growing season (Appendix IV, Table 53) was less than in the corresponding period in 1962 and did not occur as heavy prolonged rain which has been found necessary for removal of NO_3 from the surface soil (25, 31). Leaching of NO_3 was not considered an important factor in this experiment.

Factors that were important were soil acidity, and deficiency of Ca, Mg and N on the untreated soil.

Mg Content and Uptake.

The effects of treatments on the content and total uptake of Mg by oats are shown in Figs. 21 and 22. Both uptake and content were greatly increased by application of $MgSO_4.7H_2O$ to the soil. Without added Mg, plant Mg content remained very low ($< 0.1\%$) which is not surprising considering the low "available" Mg content of the soil (1.6 mg/100 g soil).

Before discussing the effect of N and $CaCO_3$ on Mg absorption, it is necessary to consider how these treatments affected the mineral N content of the soil. N added as $Ca(NO_3)_2$ probably remained as NO_3 and/

FIG. 21. Effect of treatments on the Mg content of oats, (1963).

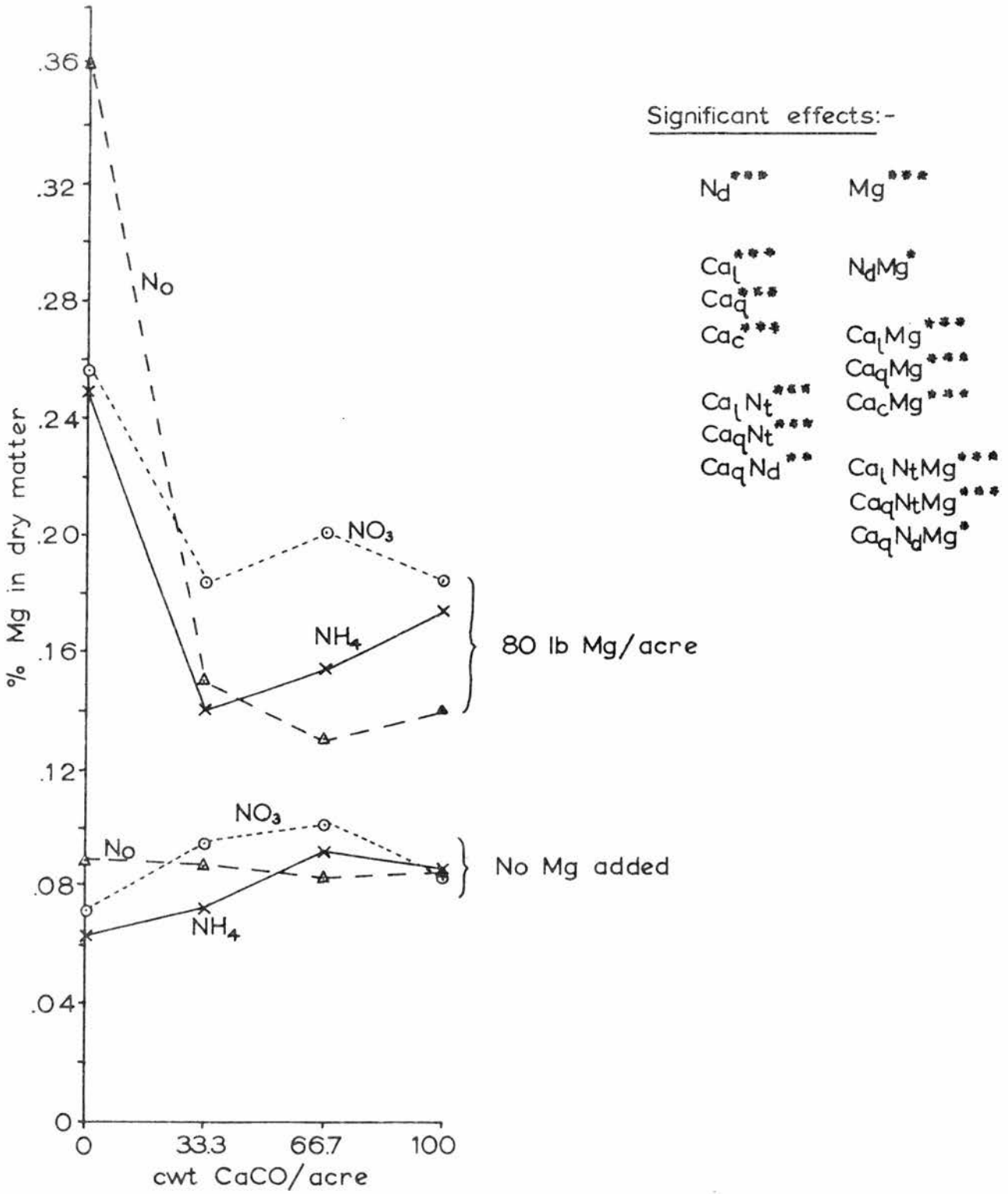
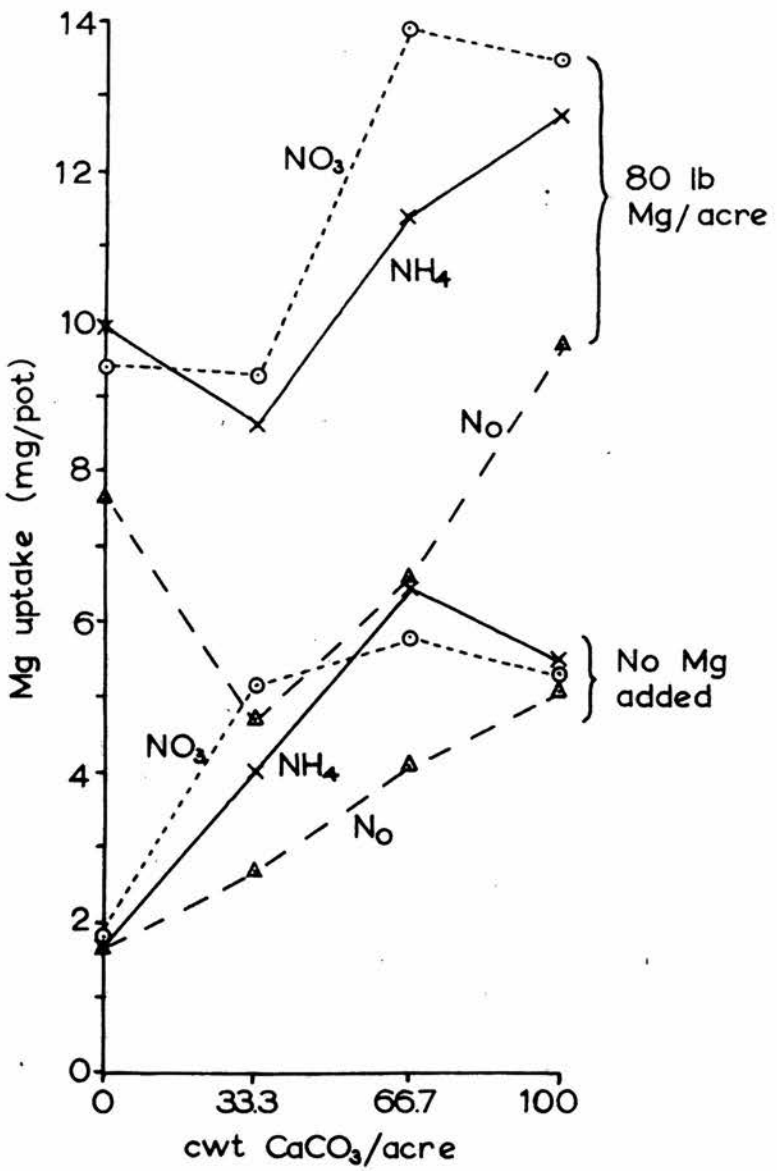


FIG. 22. Effect of treatments on the Mg uptake of oats, (1963).



Significant effects:-

N_t^{***}	Mg^{***}
N_d^{*}	
	$N_t Mg^{***}$
Ca_l^{***}	
Ca_c^{***}	$Ca_q Mg^{***}$
	$Ca_c Mg^{**}$
$Ca_q N_t^{***}$	
$Ca_q N_d^{*}$	$Ca_l N_d Mg^{*}$
	$Ca_c N_d Mg^{*}$

and was absorbed by the oats in this form, but some of the N added to the soil as $(NH_4)_2SO_4$ was converted to NO_3. The rate of conversion depended to a large extent on how the pH of the soil was increased by $CaCO_3$, as indicated by the results of mineral N analysis of the soil at the end of the experiment.

The amount of mineral N in the soil at any particular time is controlled by the rate at which it is produced by mineralisation of organic matter in the soil or by addition of fertiliser, and the rate of removal by crops, soil organisms, fixation and leaching. The proportion of NH_4 to NO_3 depends mainly on the relative uptake of these ions by the plants, the rate at which NH_4 is converted to NO_3, and the rate of loss of NO_3 by leaching. With all these factors operating together, it is difficult to interpret the results of mineral N analysis of the soil, when only one series of samples were analysed. Nevertheless, the high NH_4-N content in the soil at the end of the experiment following application of $(NH_4)_2SO_4$ without $CaCO_3$, indicated that nitrification of the NH_4 was slow at low pH (Fig. 23). This, and the high NO_3-N content following $Ca(NO_3)_2$ application without $CaCO_3$ (Fig. 24) also reflected the low uptake of N as a result of poor growth in the acid soil.

Apart from the high mineral N content of the soil resulting from poor growth where no $CaCO_3$ was added, application of $CaCO_3$ appeared to increase the rate of mineralisation of soil organic matter, as the mineral N content of the soil (both NH_4 and NO_3) increased with rate

of/

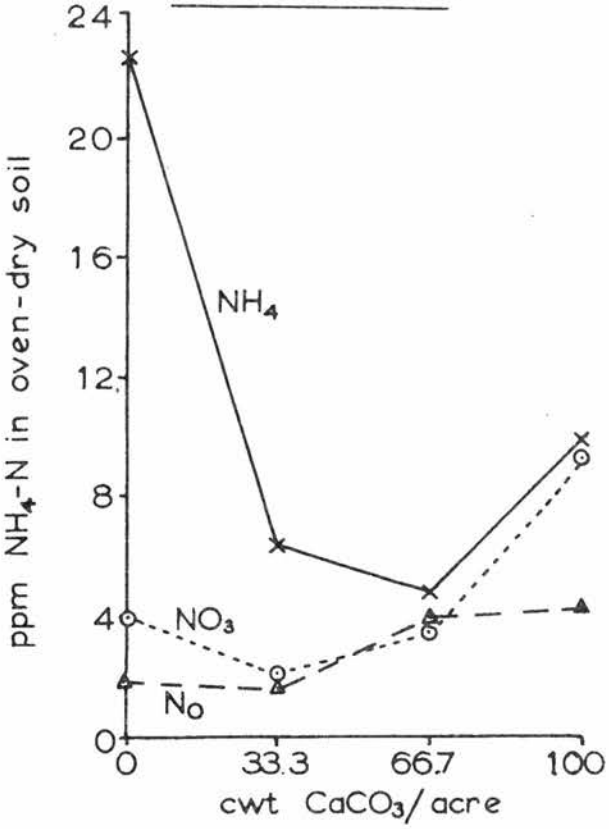
of liming despite the increased crop uptake of N. The increase was not so noticeable where no N was added because, in this case, growth was restricted by lack of N and most of the N mineralised was quickly absorbed.

As liming increased the rate of mineralisation of soil organic matter, it is reasonable to assume that the rate of nitrification of added NH_4 would also increase when the pH of the soil was raised. This assumption is supported by the results of a small incubation test carried out in the laboratory after completion of the main experiment, using a method adapted from that of Hamence (37). The results given in Fig. 25 show that nitrification of added $(NH_4)_2SO_4$ was slow at pH 4.5 but proceeded much more rapidly at pH 7.3. At ph 7.3 almost 95% of the N added in the $(NH_4)_2SO_4$ was in the form of NO_3 after 14 days incubation, compared with only 13% at pH 4.5 after 21 days. Increasing the pH also increased the rate of mineralisation of organic N in the soil (Fig. 26). Not all the added N could be accounted for by the NH_4 and NO_3 determinations. This was partly due to the fact that the method of soil extraction did not remove all the mineral N from the soil, but there were other losses which may have been caused by fixation of NH_4 (97).

Mg uptake may be influenced by the effect of pH on the absorption of NH_4 and NO_3 by the plant. High soil acidity appears to restrict the absorption of NH_4, which is taken up by the plant more readily in neutral or alkaline conditions. On the other hand, the absorption

of/

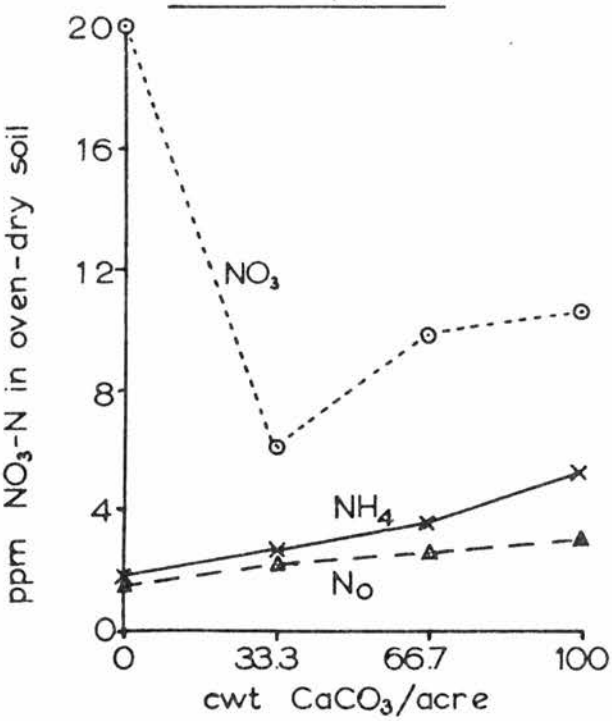
FIG. 23. Effect of $CaCO_3$, $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ on the NH_4-N content of the soil, (1963).



Significant effects:-

Nt ***	Ca_lNt *
Nd ***	Ca_qNt ***
	Ca_lNd ***
Caq ***	CaqNd **

FIG. 24. Effect of $CaCO_3$, $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ on the NO_3-N content of the soil, (1963).



Significant effects:-

Nt ***	Ca_qNt *
Nd ***	Ca_lNd ***
	CaqNd **
Caq **	CacNd *

FIG. 25. Effect of $CaCO_3$ on nitrification of applied $(NH_4)_2SO_4$ in the soil, (1963).

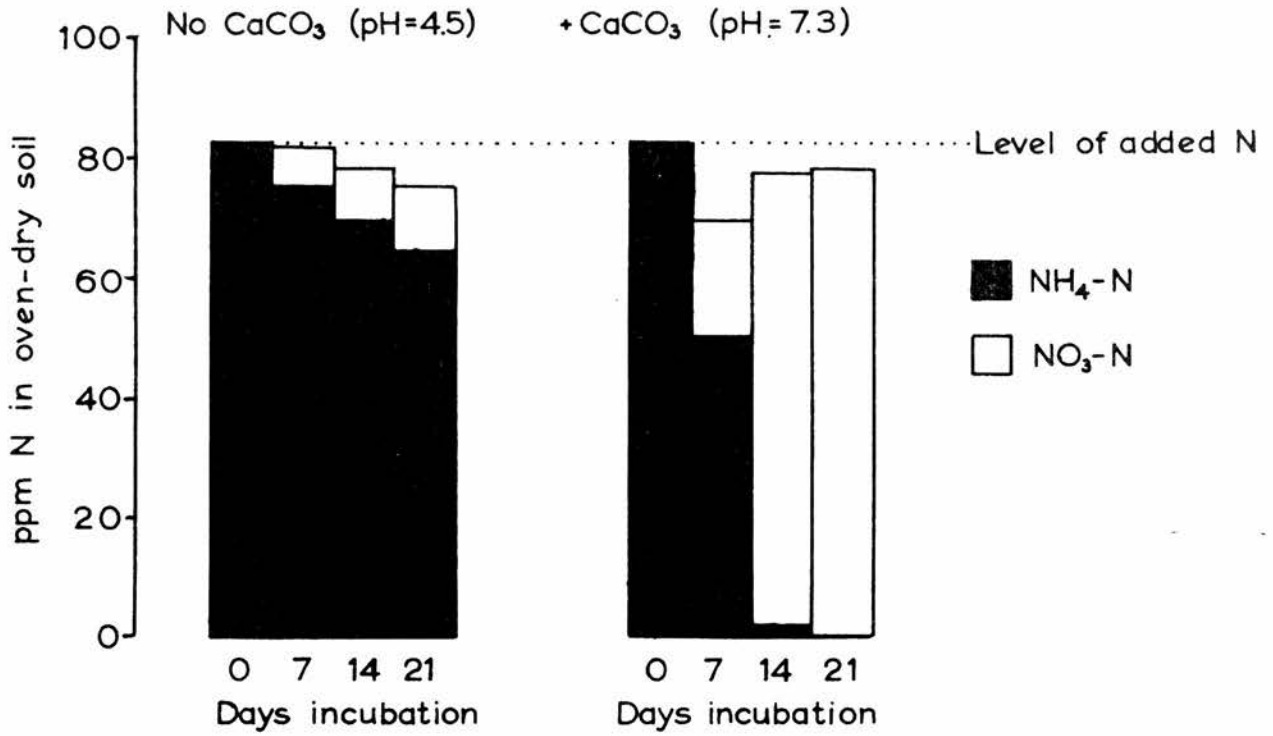
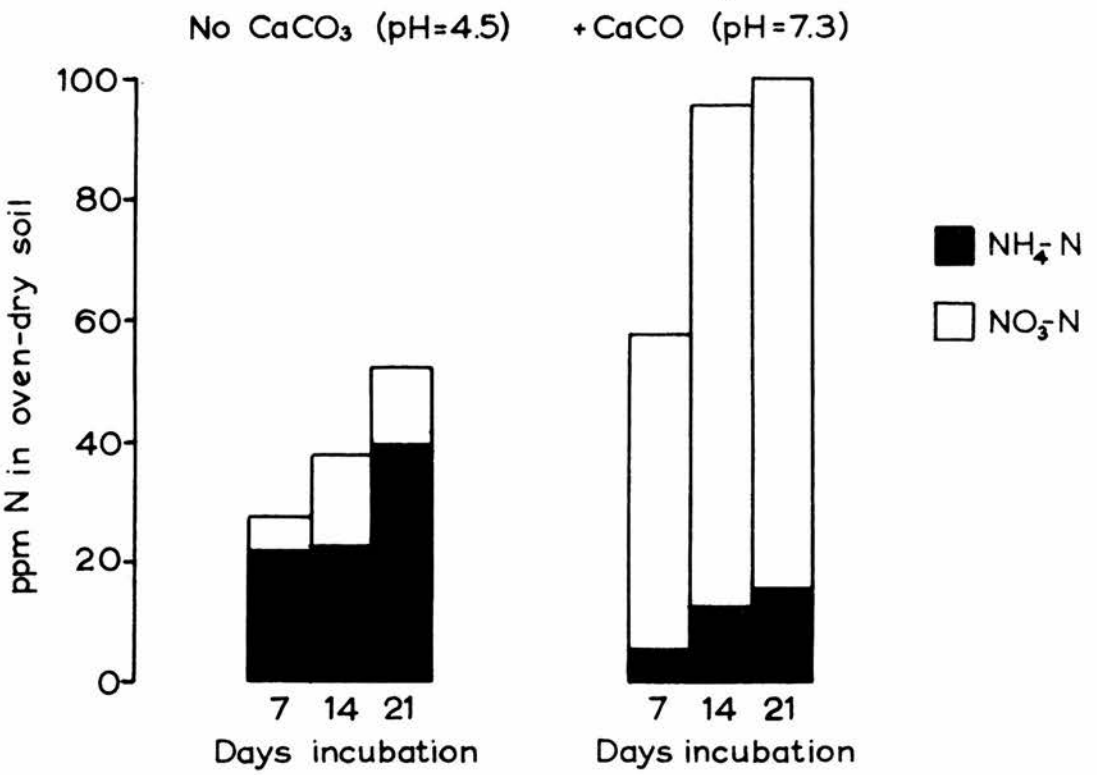


FIG. 26. Effect of $CaCO_3$ on mineralisation of organic N in the soil,(1963).



of NO_3 is not affected to the same extent by pH although it may be more rapid in slightly acid conditions (2, 91, 106, 147, 154). The actual pH at which absorption of NH_4 and NO_3 is most rapid appears to depend to a large extent on plant species. Just what effect this would have had on the absorption of Mg by the oats is not known, but it may have modified the effect of nitrification.

The results of mineral N analysis show that at low pH where nitrification was slow, N added as $(NH_4)_2SO_4$ remained to a large extent as NH_4 and was probably absorbed by the oats mainly in that form. It was concluded that the depression in Mg content of oats growing on the unlimed soil (pH 4.5) and with 33.3 cwt $CaCO_3$/acre (pH 5.7) following application of $(NH_4)_2SO_4$ was therefore due to NH_4-Mg antagonism. However, despite the reduced Mg content, the increase in yield that followed the $(NH_4)_2SO_4$ application resulted in increased total uptake of Mg. Application of $CaCO_3$ at 66.7 and 100 cwt/acre produced pH levels favourable for nitrification (pH 6.5 and 7.0) and the increased Mg content of plants grown at these pH levels was probably the result of a NO_3 effect following nitrification of the NH_4.

The beneficial effect of $Ca(NO_3)_2$ on increasing Mg content occurred only where $CaCO_3$ was also added. In the absence of $CaCO_3$, the oats were apparently unable to absorb enough Mg to keep pace with the increase in growth resulting from the $Ca(NO_3)_2$ application. The poor absorption of Mg on the unlimed soil was due mainly to the low content of "available" Mg in the soil, but the condition was aggravated by acidity/

acidity which affected the development and functioning of the roots.

Both forms of N increased total uptake of Mg, especially where $CaCO_3$ was applied at 33.3 and 66.7 cwt/acre. In general, the effects of N and $CaCO_3$ on Mg content and uptake were similar, although differing in degree, whether Mg was added or not. However, addition of Mg resulted in high Mg content and total Mg uptake of oats growing on the unlimed soil. This was luxury consumption of Mg by plants restricted in growth by acidity and lack of Ca, but having a good supply of readily available Mg. Where 33.3 cwt $CaCO_3$/acre was applied, Ca-Mg ion antagonism resulted in reduced content and total absorption of Mg, but the antagonism had no adverse effect on growth. In fact, growth was greatly increased by liming, and it was only because luxury consumption of Mg occurred on the unlimed soil that the antagonism became obvious. Application of 66.7 or 100 cwt $CaCO_3$/acre greatly increased the total uptake of Mg.

Where no Mg was applied, all levels of added $CaCO_3$ increased total Mg uptake, and Mg content was also increased in the presence of either form of added N. In the greenhouse pot-test, $CaCO_3$ equivalent to 100 cwt/acre greatly increased both content and total uptake of Mg by oats at the 4 leaf stage (Table 12).

As already mentioned in discussing the results of the 1962 barley experiment, one effect of $CaCO_3$ application is displacement of Mg from the base exchange complex in the soil, and this may make the Mg more available for absorption by plants or loss by leaching. Much of the reduction/

reduction in the Mg content of the soil to which $CaCO_3$ had been applied (Figs. 30, 31) was undoubtedly due to leaching losses. In the greenhouse pot-test, where watering was controlled to reduce drainage from the pots to a minimum, application of $CaCO_3$ had little effect on the content of "available" Mg in the soil (Table 12).

$CaCO_3$ application increased the rate of mineralisation of organic N and the rate of nitrification of NH_4 in the soil (Figs. 23 - 26) and as a result, Mg absorption by the oats may have been increased. Decomposition of soil organic matter would also release organically bound Mg, although some of this Mg would be required by the bacteria breaking down the organic matter.

Direct H ion competition was not considered an important factor influencing Mg absorption on the unlimed soil in the 1962 barley experiment. However, H-Mg antagonism cannot be discounted in the present oat experiment as the pH of the unlimed soil (pH 4.6) is approaching the level below which H-Mg antagonism is reported to have an adverse effect on Mg absorption (4, 5, 84, 128, 152), and part of the increase in Mg content of the oats on addition of $CaCO_3$ may have resulted from removal of H ion competition.

The increased growth and better root development after liming, bringing the roots into contact with a greater volume of soil from which they could obtain Mg, greatly increased total Mg absorption by oats, and may have contributed to the increased Mg content. These beneficial effects of $CaCO_3$ application apparently exerted more

influence/

influence on Mg absorption than did Ca-Mg antagonism.

There are many reports in the literature of applied lime increasing the Mg content of plants, despite Ca-Mg antagonism (1, 10, 40, 56, 70, 102, 110, 111, 157). When plant Mg content was increased by liming the soil, the initial pH of the soil was usually low (as was the case in this experiment), so that the effects of increased pH must be considered. Other evidence indicates that if soil pH is near or above neutrality, plant Mg content may be decreased by application of lime (1, 93, 94, 102, 131, 157). For example, Naftel (93, 94) found that a small application of pure $CaCO_3$ which increased the pH of various acid soils from pH 4.2 - 5.5 to pH 6.2 - 6.4, increased the Mg content of sorghum grown 12 months later, but higher applications of $CaCO_3$ which increased the pH up to 7.5 - 7.9, reduced the Mg content.

No such reduction in Mg content was observed in this experiment but there was an indication that Ca-Mg antagonism was becoming important where the rate of $CaCO_3$ application was 100 cwt/acre, as Mg content and uptake were in some cases lower than at the 66.7 cwt rate. Reduced Mg uptake was accompanied by a continued increase in Ca uptake. The increase in yield resulting from applied $CaCO_3$ also tended to fall off at the highest rate of application, particularly in the absence of added Mg.

Because $CaCO_3$ influences the absorption of Mg in several ways, the effect of Ca-Mg antagonism was not always obvious. However, the antagonism/

antagonism was clearly shown in reduced Mg content of oats grown in the greenhouse pot-test (Table 12) where Ca was applied as $CaSO_4.2H_2O$. In this case, the complications of varying pH and the resulting effects were much reduced. Total Mg uptake was also decreased by $CaSO_4.2H_2O$, despite increased yield. Reductions in Mg content of plants as a result of $CaSO_4.2H_2O$ applications have been reported by several workers, including Mehlich and Reed (82) and Plant (107).

The effects of Ca-Mg antagonism were also evident in the reduced Ca content of oats following application of $MgSO_4.7H_2O$ to the soil (Table 13), but as yield was also increased, there was no effect on total Ca uptake.

Table 13. Effect of $MgSO_4.7H_2O$ on the % Ca content of oats (1963).

lb Mg/acre	cwt $CaCO_3$/acre				Significant	effects
	0	33.3	66.7	100		
0	0.36	0.65	0.72	0.76	Ca_l^{***}	Mg^{***}
					Ca_q^{***}	
80	0.27	0.64	0.61	0.72	Ca_c^{***}	Ca_cMg^{*}

Several workers, including Dijkshoorn (26) and van Itallie (56, 57) have shown that the antagonistic effect of the Ca ion on Mg absorption is not so strong as that of the K or Na ions, and applications of Mg have been found to decrease Ca absorption to a greater/

greater extent than equivalent applications of Ca decreased Mg absorption (36, 57). This weak competitive effect of Ca was evident in the results of both the 1962 and 1963 pot experiments. Application of $MgSO_4.7H_2O$ which increased the Mg content and had no effect on the K and Na contents of oats, decreased the Ca content (Table 14).

Table 14. Effect of $MgSO_4.7H_2O$ on the cation content of oats.

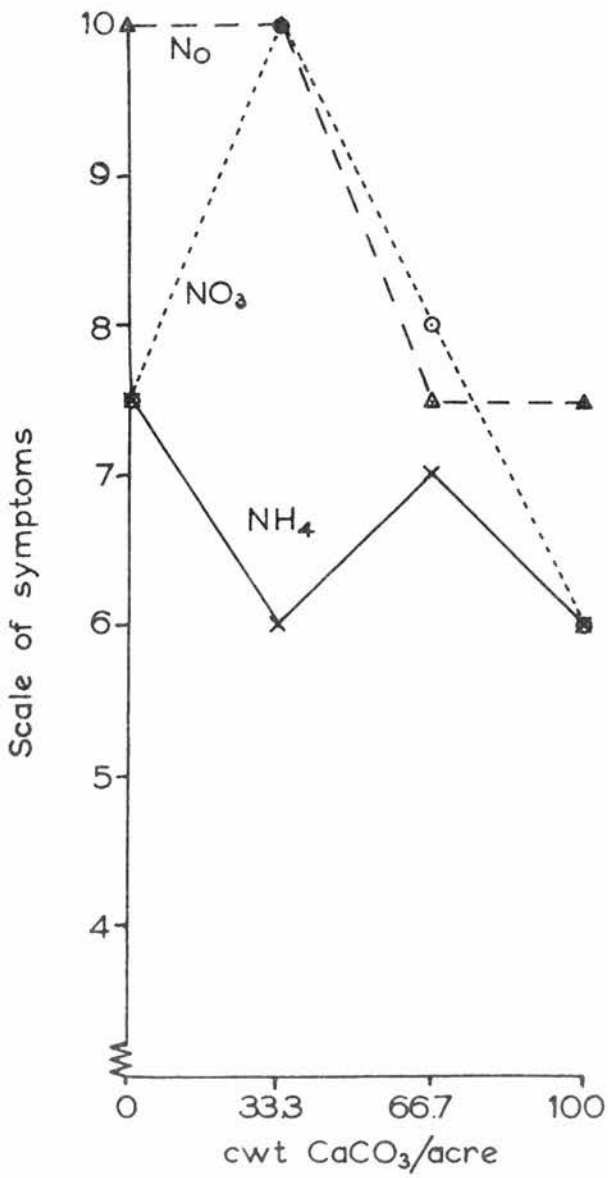
Cation content % in D M	5-6 leaf stage - 1962 expt.				4-5 leaf stage - 1963 expt.		
	lb Mg/acre			Significant effects	lb Mg/acre		Significant effects
	0	60	120		0	80	
K	2.80	2.70	2.74	N.S.	3.15	3.16	N.S.
Na	.097	.097	.104	N.S.	.077	.082	N.S.
Ca	0.43	0.40	0.39	Mg_1^{**}	0.62	0.56	Mg^{***}
Mg	.171	.187	.197	Mg_1^{***}	.085	.193	Mg^{***}

Mg Deficiency Symptoms.

Where $MgSO_4.7H_2O$ was applied, no symptoms of Mg deficiency were observed and the lowest Mg content found was 0.13%, but in the absence of Mg, the Mg contents of the oats were lower than 0.10% and symptoms of deficiency occurred frequently. The results of visual observations of symptoms taken on 29 May and 5 June were similar (Fig. 27, 28), all main effects and interactions being highly significant, but the symptoms were generally less severe at the second observation, except on the unlimed soil where symptoms became more severe (Fig. 29).

Temporary/

FIG. 27. Effect of treatments on Mg deficiency symptoms of oats in the absence of added Mg, (29 May 1963).

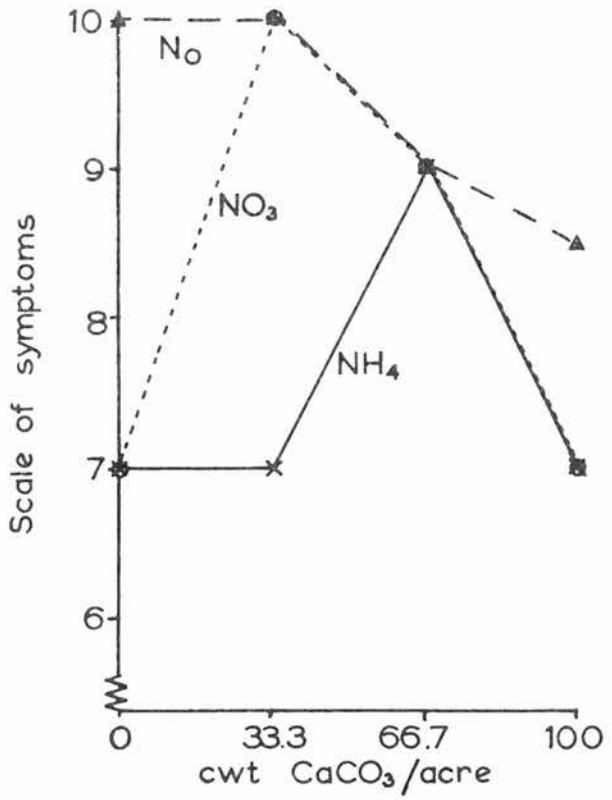


Significant effects:- (including Mg)

N_t^{***}	Mg^{***}
N_d^{***}	
	$N_t Mg^{***}$
Ca_l^{***}	$N_d Mg^{***}$
Ca_q^{***}	
Ca_c^{*}	$Ca_l Mg^{***}$
	$Ca_q Mg^{***}$
$Ca_l N_t^{**}$	$Ca_c Mg^{*}$
$Ca_q N_t^{**}$	
$Ca_c N_t^{**}$	$Ca_l N_t Mg^{**}$
$Ca_q N_d^{***}$	$Ca_q N_t Mg^{**}$
$Ca_c N_d^{***}$	$Ca_c N_t Mg^{**}$
	$Ca_q N_d Mg^{***}$
	$Ca_c N_d Mg^{**}$

Note:- The scale of assessment and description of Mg deficiency symptoms are given on pages 34 and 35.

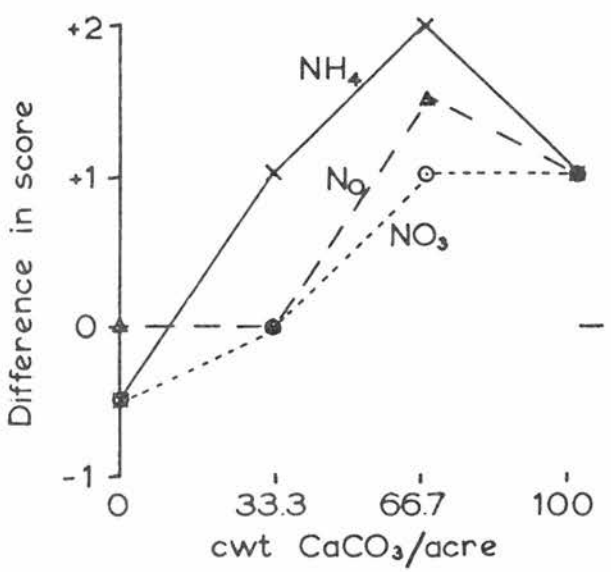
FIG. 28. Effect of treatments on Mg deficiency symptoms of oats in the absence of added Mg, (5 June 1963).



Significant effects:-
(including Mg)

Nt***	Mg***
Nd***	
	Cal Mg***
Cal***	Caq Mg***
Caq***	
	Nt Mg***
Cal Nt***	Nd Mg***
Caq Nt***	
Cac Nt***	Cal Nt Mg***
Cal Nd**	Caq Nt Mg***
Caq Nd***	Cac Nt Mg***
Cac Nd***	Cal Nd Mg**
	Caq Nd Mg***
	Cac Nd Mg***

FIG. 29. Effect of advancing season on the severity of Mg deficiency symptoms in the absence of added Mg.



The data for this graph were obtained by subtracting the symptom scores of 5 June from the corresponding scores of 29 May.

Significant effects:-
(including Mg)

Nd*	Mg***	Cal Mg***
		Caq Mg***
Cal***	Nd Mg*	Cac Mg**
Caq***		
Cac**	Caq Nd*	Caq Nd Mg*

Temporary appearance of Mg deficiency symptoms in spring cereals has been reported by several workers (39, 125, 133). Harrod and Caldwell (39) reported that over 75% of the cases of Mg deficiency symptoms in spring cereals in East Anglia were due to slow formation of secondary roots after decay of the primary rooting system. The appearance of the symptoms often coincided with periods of very cold dry weather which greatly hindered root development, and the symptoms generally disappeared when the climatic conditions improved. It was only in very severe cases that application of Mg had any effect on yield. This is in agreement with observations of Ferrari and Sluijsmans (29) who found that mild symptoms of Mg deficiency in oats were not associated with a reduction in final yield.

In the present experiment, the reduction in the severity of the Mg deficiency symptoms occurred at a time when the oats were growing very rapidly, but the improved development of the root system was apparently able to take care of the rapidly increasing requirement of the plants for Mg. Scharrer and Mengel (125) reported that very rapid growth of spring barley and oats resulting in a temporary low content of Mg may cause transient symptoms of Mg deficiency at the tillering stage.

Although Mg deficiency symptoms in the oats at the first observation were generally more severe following application of $CaCO_3$ to the soil, the reduction in the severity of the symptoms between the two observations was greater than in oats growing on the unlimed/

unlimed soil (Fig. 29). This effect, which has been previously reported by Smit and Mulder (133), may have resulted from better root development where $CaCO_3$ had been applied. On the unlimed soil, where the root system was very poorly developed, symptoms of Mg deficiency were more severe at the second than at the first observation.

Although it would appear safe to conclude from the results of this experiment and from the results of some other experiments reported in the literature, that young oats with visible signs of Mg deficiency are likely to have Mg contents < 0.1% in the dry matter, van Itallie (55, 56) has reported Mg contents as high as 0.25% in oats showing Mg deficiency symptoms. Levels of Mg, which have been found by other workers in oats showing symptoms of Mg deficiency are presented in Table 15 together with the range found in this experiment. It is evident that factors other than Mg content are involved. Some of the variations were undoubtedly due to differences in stage of growth which greatly influences Mg content as the results of the 1962 experiments have shown. There may also have been seasonal and varietal differences, and there is some evidence to suggest that the severity of Mg deficiency symptoms at a particular level of Mg in the foliage may depend on the concentration of other elements present (29, 153).

Table 15./

Table 15. Mg contents of healthy and Mg-deficient oat plants.

Reference	Stage of growth	% Mg in DM	Health of plants
1963 Expt.	4-5 leaf	.061 - .102	Deficiency symptoms
		.078 - .368	No symptoms
1963 Pot-test	4 leaf	.098	Slight symptoms
		.119 - .189	No symptoms
Ferrari and Sluijsmans (29)	Young plants (10-30 cm)	< .11 - .13	Deficiency symptoms
van Itallie (55)	Young plants (April - May)	.10 - .39	Deficiency symptoms
		.18 - .52	No symptoms
van Itallie (56)	4-6 leaf	< .097	Severe symptoms
		.073 - .255	Deficiency symptoms
		.127 - .286	No symptoms
Nicholas (96)	Young plants	0.09	Mg deficient
		0.34	Healthy
Scharrer and Mengel (125)	Tillering stage	< .0125 in fresh material	Marked deficiency symptoms
Seo (130)	(not given)	< .09	Deficiency symptoms

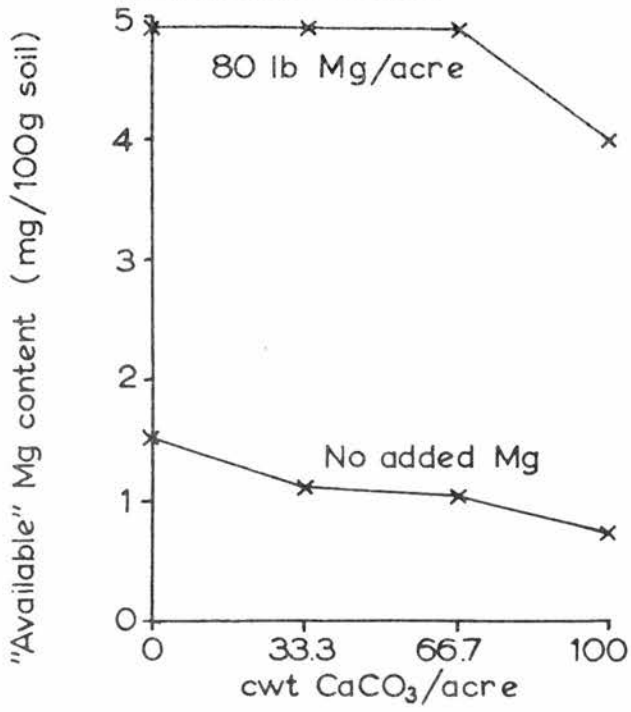
In this experiment, no attempt was made to correlate the effects of varying concentrations of other elements in the oats with the severity of the Mg deficiency symptoms, as all these factors were affected to a highly significant degree by the treatments and any positive correlation obtained between, for example, Ca content and the severity of the Mg deficiency symptoms would simply mean that the treatments affected the Ca content and the severity of the symptoms in a similar way.

Soil Mg Content.

Treatments significantly affecting the "available" Mg content of the soil are shown in Fig. 30. The reduction in Mg content following application of $CaCO_3$ was probably due to loss of Mg in the drainage water and to greater plant uptake as a result of improved growth although only a small fraction of the reduction was due to plant uptake. As Mg lost in the drainage water was not determined, it is not known if there was any fixation of Mg, but it is unlikely that fixation occurred on this very sandy soil. In the greenhouse pot-test where it was possible to control the watering of the pots so that little or no drainage occurred, the small reduction in "available" Mg content in the soil following $CaCO_3$ application (Table 12) can be accounted for by increased plant uptake. The loss of "available" Mg during the course of the experiment was therefore probably a measure of the loss of Mg in the drainage water. It was affected by the same treatments that affected

soil/

FIG. 30. Effect of $CaCO_3$ and $MgSO_4.7H_2O$ on the "available" Mg content of the soil, (1963).



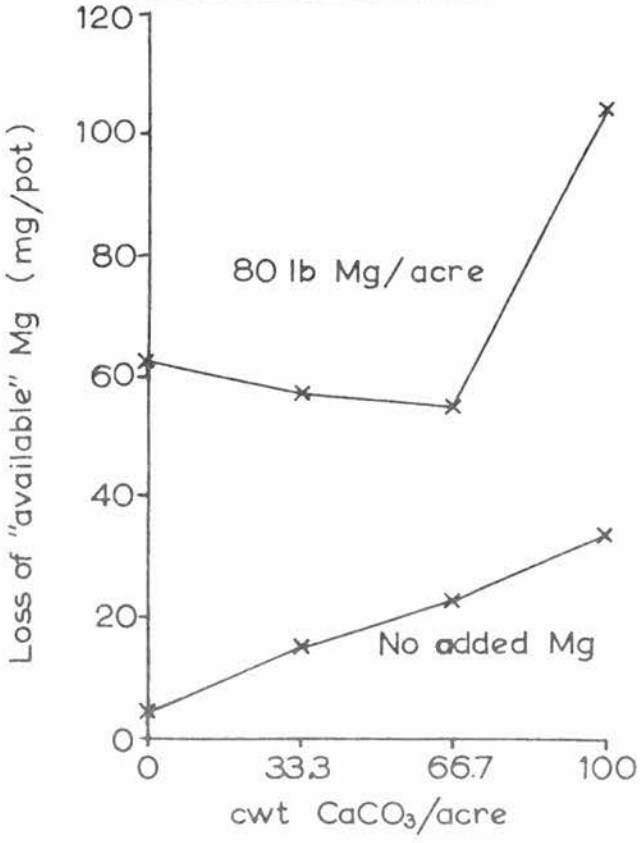
Significant effects:-

Ca_l ***

Mg ***

Ca_qMg *

FIG. 31. Effect of $CaCO_3$ and $MgSO_4.7H_2O$ on the loss of "available" Mg from the soil, (1963).



Significant effects:-

Ca_l ***

Ca_q *

Mg ***

Ca_qMg *

soil Mg content (Fig. 31).

Several workers have reported that continued application of $(NH_4)_2SO_4$ reduced the content of "available" Mg in soils and increased the loss of Mg in drainage water (14, 87, 161), but neither $(NH_4)_2SO_4$ nor $Ca(NO_3)_2$ application, although they increased the Mg uptake of oats, had any effect either on soil Mg content or on the loss of "available" Mg from the soil in the short time during which this experiment was carried out.

The content of "available" Mg in the soil was very low (1.6 mg/100 g soil) and the dry matter yield of oats was increased by application of $MgSO_4.7H_2O$. An increase in yield following Mg application was expected, as the limiting levels of soil Mg ("available," readily soluble, or exchangeable) reported in the literature, below which a yield response to added Mg may occur, are mostly well above 1.6 mg Mg/100 g soil.

Many different limiting levels have been reported ranging from about 2 to 12 mg Mg/100 g soil (35, 48, 67, 80, 85, 112, 122, 132, 158). The most commonly reported level is 5 mg/100 g soil. Reith (112) concluded from a series of experiments that the readily soluble Mg content of the soil would have to be less than 5 mg/100 g soil before a yield response to added Mg could be expected, and that the common agricultural crops are unlikely to respond if the soil contains more than 3 mg Mg/100 g soil. Purves (172) determined the exchangeable Mg content in 100 samples of soil from randomly selected fields of temporary grass in South-East Scotland. 11% of the soils analysed had exchangeable Mg contents < 3 mg/100 g soil.

The/

The fact that plants differ in their requirements for Mg and in their ability to absorb Mg from soils, accounts for some of the variations in the reported limiting levels of soil Mg, but one of the greatest difficulties is to find a simple adequate method for assessing the Mg status of the soil. The methods commonly used to measure the availability of soil Mg are largely empirical and, although it may be possible to relate exchangeable soil Mg to the Mg uptake by plants, the amount of Mg exchanged depends on the exchange solution used, and no indication is given of the relative bonding energy or the ease of replacement of Mg in relation to other ions. It is not surprising, therefore, that the exchangeable soil Mg contents are often poorly correlated with plant Mg contents.

In recent years, attention has been directed towards research into more fundamental properties of soils and it is hoped that this work will lead to the development of a reliable method of assessing the availability of Mg. Several authors have proposed that various ion activity ratios in solutions in equilibrium with the soil may be used to estimate nutrient availability (165, 166, 168, 175, 178, 179, 180). For example, the labile Mg status of soils in which the dominant cations are Ca and Mg may be given by the activity ratios a_{Mg}/a_{Ca} or a_{Mg}/a_{Ca+Mg} (166, 175). These simple activity ratios do not define the Mg status completely: they measure the labile Mg in the soil (relative to Ca, or Ca+Mg) at the time of measurement only and, as with measurements of exchangeable soil Mg, they/

they give no indication of how the availability of Mg might be affected by variations in pH level or by the competitive antagonism of other cations such as K. However, Salmon and Arnold (174) have shown that it may be possible to account for these effects by the use of various "proportionality" factors. They found that ion activity ratios which incorporated "proportionality" factors to take care of variations in pH and soil K content were well correlated with the Mg contents of ryegrass grown on 41 different soils in a greenhouse experiment. The Mg contents of the ryegrass were poorly correlated with the exchangeable Mg contents of the soils. Another difficulty encountered in relating plant composition to cation activity ratios is that soils with the same activity ratio do not necessarily have the same capacity to maintain the ratio while Mg is being removed by crops or leaching (167, 169, 174). Salmon (173) found that the rate at which the activity ratios were altered by changes in the labile Mg content of the soil varied widely for different soils.

This work has so far been carried out only under controlled conditions in greenhouse experiments, and although its agronomic value is still unknown, an investigation of this kind provides much more information about the properties of soils than empirical experimentation.

V. GENERAL DISCUSSION AND CONCLUSIONS.

The effect of N on Mg absorption depends on the form in which the N is absorbed. Work with culture solutions where the N was absorbed by the plant in the form in which it was added has clearly shown that the NO_3 ion exerts a beneficial effect on Mg absorption and that the NH_4 ion is antagonistic and inhibits the absorption of Mg. The position is more complicated where soil is the nutrient medium.

In this series of experiments, a reduction in the Mg content of oats as a result of NH_4-Mg antagonism was observed only following application of $(NH_4)_2SO_4$ to an acid soil in which nitrification of NH_4 was slow. However, reduced Mg content is not necessarily accompanied by reduced total uptake of Mg. On a N-deficient soil where application of $(NH_4)_2SO_4$ greatly increased yield, the total absorption of Mg was increased despite the reduction in Mg content.

No reduction in Mg content was observed where $(NH_4)_2SO_4$ was applied to neutral or slightly acid soils, or to acid soils to which $CaCO_3$ was also added. In these soils, nitrification of NH_4 was rapid. It was concluded, therefore, that the increased Mg content and total Mg uptake of oats and barley obtained on application of $(NH_4)_2SO_4$ to non-acid soils, and on application of $(NH_4)_2SO_4$ and $CaCO_3$ to acid soils, were results of a NO_3 effect following nitrification of the NH_4.

Application of $Ca(NO_3)_2$ and $NaNO_3$ increased Mg content and total Mg uptake of oats and barley growing on both acid and neutral soils. The results/

results obtained in this series of experiments are in agreement with those of other workers, which show that the relative effects of different nitrates on Mg absorption depend on the antagonism of the cation added with the NO_3. The stronger the antagonism of the cation, the smaller is the increase in Mg content. The order of efficiency of nitrates in increasing Mg content is, therefore —

$$Mg(NO_3)_2 > Ca(NO_3)_2 > NaNO_3 > KNO_3$$

Increasing antagonism of the cation towards Mg.

If none of these cations is limiting growth and NO_3 application increases yield to the same extent in each case, the increase in total Mg uptake will be in the same order. The position of NH_4 salts in the above series will depend to a large extent on their effect on yield and on the rate of nitrification in the soil.

K is antagonistic towards Mg and application of KCl to the soil reduced the Mg content of the oats. As K had no effect on yield, total Mg uptake was also reduced. Had yield been increased by application of KCl, total Mg uptake might also have been increased despite the antagonistic effect of the K ion on Mg absorption. K-Mg antagonism was not reflected in reduced yield of oats, as the soils to which K was applied had moderate and satisfactory "available" Mg contents (6.1 and 11.7 mg/100 g soil). It is only when the soil Mg content is low (< 5 mg/100 g soil) that the antagonistic effect of K may result in lower/

lower yields by inducing Mg deficiency.

Other adverse effects of K applications often reported in the literature are reduced "available" Mg content of the soil, and increased loss of Mg in the drainage water. In this series of experiments, no reduction in "available" Mg content was observed. No attempt was made to measure the amount of Mg lost in the drainage water.

Like K, Na is antagonistic towards Mg. In the present series of experiments, soil applications of $Ca(NO_3)_2$ increased the Mg content of oats to a greater extent than did $(NH_4)_2SO_4$. The Mg content of barley was increased to a lesser extent by addition of $NaNO_3$ to the soil than by addition of $(NH_4)_2SO_4$. Soil applications of $MgSO_4.7H_2O$ which increased the Mg content and decreased the Ca content of oats, had no effect on their K and Na contents. Although these results do not permit direct comparison of the effects of Na with those of K, Ca and Mg, they are in agreement with the results of other workers which have indicated that the antagonistic strength of the Na ion is greater than that of either Ca or Mg, and that Na exerts almost as much influence in inhibiting the absorption of Mg as does K.

Ca is antagonistic towards the Mg ion. The antagonism was most clearly seen in reduced content and total uptake of Mg by oats where Ca was added to the soil in a neutral salt such as $CaSO_4.2H_2O$. However, Ca is often applied in some form of lime, which, by raising the pH of the soil, causes many effects not directly attributable to the Ca.

In/

In this series of experiments, application of calciferous limestone and pure $CaCO_3$ to acid soils, generally increased both Mg content and total Mg uptake of barley and oats, despite the antagonistic effect of the added Ca on Mg absorption. Similar results have been reported by other workers. There are several causes which may have contributed to increased Mg absorption.

1. Following the removal of such harmful factors as high concentrations of Al, Mn and H ions, improved plant growth and development would bring the roots into contact with a much greater volume of soil from which they could obtain Mg.

2. Improved microbiological activity in the soil would increase the rate of release of Mg from soil organic matter, although some of this Mg would be required by the bacteria breaking down the organic matter. The rate of conversion of NH_4 (which inhibits Mg absorption) to NO_3 (which increases Mg absorption) was increased by liming acid soils.

3. Displacement of Mg from the base exchange complex in the soil following the addition of $CaCO_3$ may have made the Mg more available to be taken up by plants or lost by leaching.

4. In the barley experiment, some Mg was added to the soil in the calciferous limestone.

It is not known to what extent each of these factors was involved, but some of them apparently exerted more influence on the absorption of Mg than did Ca-Mg antagonism. The increase in plant Mg content was a short term effect of liming acid soils. As none of the experiments was continued/

continued for more than one season, no evidence was obtained about the long term effects of liming.

The results of the 1963 oat experiment indicate that the effects of Ca-Mg antagonism are likely to become more important where very high rates of $CaCO_3$ are applied, and in fact, reduction in plant Mg content due to Ca-Mg antagonism has been reported by several workers. These results have led to the general conclusion that if acid soils are overlimed, or if lime is applied to alkaline, neutral or slightly acid soils well supplied with Ca, plant Mg content may be reduced due to the antagonistic effect of the Ca present in the lime, which in this case does not have all the beneficial effects that it has on acid soils. Reduction in Mg content is not necessarily accompanied by a reduction in total Mg uptake if the application of lime increases yield.

Application of $MgSO_4.7H_2O$ to the soil increased the Mg content and total Mg uptake of oats, but except where the Mg content of the soil was very low, there was no increase in yield of dry matter.

No information was obtained on the mechanisms involved in Mg absorption by plants: the experiments were not designed to provide such information. The practical and theoretical problems encountered in a study of ion absorption are very complex, as Dainty (170) has pointed out in a review of some recent investigations. Not only are ions passively transported across cell membranes as a result of differences in electrochemical potentials, but they can be actively accumulated at concentrations many times greater than those of the external medium by the/

the operation of "ion pumps." Ions are "pumped" into the cells by some form of active transport mechanism which obtains energy from metabolism. Hypotheses of active uptake usually assume the operation of a "carrier" which combines with the ion at the outer surface of the cell. The ion-carrier complex then moves to the other side of the cell membrane where it dissociates and releases the ion (170, 171, 177).

The proper study of ion absorption based on fundamental physical and chemical principles is just beginning, and much of the work has of necessity been carried out on large single algal cells. Before the mechanisms of ion absorption can be fully understood, much more work will have to be done, particularly with higher plants, where the complexities of the plant system and the practical difficulties in making accurate measurements of ion concentrations and electrical potentials are much greater than those encountered in studying large cells.

VI. SUMMARY.

Three experiments were carried out to study the effects of fertilisers on the absorption of Mg by oats and barley.

1. The effects of $(NH_4)_2SO_4$ and ~~$Ca(NO_3)_2$~~ $NaNO_3$ applications to the soil on the Mg content of barley at various stages of growth were compared in a factorial field experiment on a slightly acid loam (pH 5.5, 6.6 mg "available" Mg/100 g soil) to which several rates of calciferous limestone had been applied. Treatments had no effect on the Mg content of grain or straw at harvest. At 4 earlier stages of growth, $(NH_4)_2SO_4$ increased the Mg content of the barley to a greater extent than did $NaNO_3$. Calciferous limestone slightly increased Mg content. Nitrification of NH_4 in the soil was rapid.

2. Oats grown in a factorial pot experiment under normal atmospheric conditions on 2 loams (pH 5.7, 7.6 and "available" Mg contents 6.1, 11.7 mg/100 g soil) were sampled at 4 stages of growth. Neither KCl nor $MgSO_4.7H_2O$ applications had any effect on yield but Mg content and uptake were consistently decreased by applied K and increased by applied Mg. N added as $Ca(NO_3)_2$ increased Mg content to a greater extent than did $(NH_4)_2SO_4$, but yield and total Mg uptake were higher where $(NH_4)_2SO_4$ was applied. The effects of fertilisers were similar on both soils.

3. The effects of $CaCO_3$, $MgSO_4.7H_2O$, $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ applications to the soil on the yield and Mg uptake of oats at the

4-5/

4-5 leaf stage were studied in a factorial pot experiment under normal atmospheric conditions with a Mg-deficient acid sandy soil (pH 4.6, 1.6 mg "available" Mg/100 g soil). Yield was increased by all treatments, particularly $CaCO_3$. Application of $CaCO_3$, $MgSO_4.7H_2O$ and $Ca(NO_3)_2$ generally increased Mg content and total Mg uptake of oats. Application of $(NH_4)_2SO_4$, which reduced the Mg content of oats on the unlimed soil, increased the Mg content where $CaCO_3$ was also added. The rate of nitrification of NH_4, which was slow in the acid soil, was greatly increased by application of $CaCO_3$. Where $MgSO_4.7H_2O$ was applied, no symptoms of Mg deficiency were observed and the Mg contents of the oats were > 0.13%, but in the absence of added Mg, the Mg contents were < 0.10% and deficiency symptoms occurred frequently. In a small experiment with the same soil, application of $CaSO_4.2H_2O$ increased the yield of oats at the 4 leaf stage, but reduced content and total uptake of Mg.

The main conclusions reached were :-

1. Application of nitrates may increase Mg content and total Mg uptake of plants: the relative effects of different nitrates depend on the antagonism of the added cation towards Mg.

2. NH_4 is antagonistic towards Mg and its application to acid soils where nitrification is slow may reduce plant Mg content, but not necessarily total Mg uptake if yield is increased.

3./

3. Application of NH_4 salts to non-acid soils may increase plant Mg content as a result of a NO_3 effect following nitrification of the NH_4.

4. Application of KCl may reduce plant Mg content, but if yield is increased total Mg uptake may also be increased, despite reduced Mg content.

5. Na is antagonistic towards Mg and appears to exert almost as much influence on Mg absorption as does K.

6. Application of $MgSO_4.7H_2O$ may increase content and total uptake of Mg, but is unlikely to increase yield unless the soil is low in "available" Mg.

7. Ca is antagonistic towards Mg, as shown by the reduced content and total Mg uptake of oats following $CaSO_4.2H_2O$ application to the soil.

8. Despite Ca-Mg antagonism, plant Mg content may be increased as a result of improved soil conditions following addition of $CaCO_3$ (or calciferous limestone) to acid soils.

9. Application of $CaCO_3$ to non-acid soils well supplied with Ca may reduce plant Mg content due to the antagonistic effect of the Ca added in the $CaCO_3$, which in this case does not have all the beneficial effects that it has on acid soils.

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Note: The method of presenting references to papers in languages other than English is that used in "Soils and Fertilisers," in which a capital letter in brackets after the reference indicates the language in which the paper is written, and a small letter denotes a summary in another language -- e.g., (G.e.) = German with English summary.

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APPENDICES

APPENDIX I. Standardisation of Methods of Analysis.

Table 16. K - error in plant analysis

Recovery 10 mg K (≡ 2%) added to 0.5 g sample of plant material

Plant Material	% K †		% Recovery
	Plant K	Plant + added K	
Maize plants	2.39	4.40	100.5
Grass	1.41	3.44	101.5
Clover	1.41	3.44	101.5
Turnip	2.91	4.91	100.0
Sugar beet tops	3.07	5.06	99.5
Sugar beet leaves	3.35	5.32	98.5
Potato foliage	0.87	2.84	98.5
Barley grains	0.48	2.49	100.5
Beans	1.10	3.07	98.5
Marrowstem kale	2.51	4.51	100.0

Replicate analysis % K

Oat plants	0.98, 0.98, 0.98, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.04
Rape	2.45, 2.48, 2.48, 2.48, 2.50, 2.50, 2.53, 2.53, 2.56, 2.56

Sampling error (barley experiment) % K

Barley plants	3.00, 3.06, 3.03, 3.09, 3.13, 3.06, 3.13, 3.06, 3.06, 3.20

† Mean of 2 determinations.

Table 17. Na - error in plant analysis.

Plant Material	% Na†		% Recovery
	Plant Na	Plant + added Na	
Recovery	1 mg Na (≡ 0.2%) added to 0.5 g sample of plant material		
Maize plants	.053	.251	99.0
Grass	.126	.324	99.0
Clover	.190	.393	101.5
Turnip	.078	.279	100.5
Sugar beet tops	.350	.553	101.5
Sugar beet leaves	1.138	1.338	100.0
Potato foliage	.075	.277	101.0
Barley grains	.020	.217	98.5
Beans	.020	.218	99.0
Marrowstem kale	.364	.569	102.5

Replicate analysis % Na

Oat plants	.148,	.151,	.151,	.153,	.156,	.158,	.158,	.158,	.158,	.160
Rape	.059,	.060,	.060,	.060,	.061,	.061,	.062,	.062,	.064,	.064

Sampling error (barley experiment) % Na

Barley plants	.053,	.053,	.059,	.050,	.057,	.055,	.053,	.053,	.057,	.048

† Mean of 2 determinations.

Table 18. Ca - error in plant analysis

Recovery 2.5 mg Ca (≡ 0.5%) added to 0.5 g sample of plant material

Plant Material	% Ca†		% Recovery
	Plant Ca	Plant + added Ca	
Maize plants	0.33	0.83	100
Grass	0.47	0.97	100
Clover	2.17	2.68	102
Turnip	0.31	0.79	96
Sugar beet tops	0.63	1.13	100
Sugar beet leaves	1.03	0.53	100
Potato foliage	3.27	3.80	106
Barley grains	0.06	0.57	102
Beans	0.13	0.63	100
Marrowstem kale	0.85	1.34	98

Replicate analysis % Ca

Oat plants	0.33, 0.34, 0.34, 0.35, 0.35, 0.35, 0.35, 0.35, 0.35, 0.36
Rape	0.92, 0.94, 0.94, 0.94, 0.95, 0.95, 0.96, 0.96, 0.96, 0.98

Sampling error (barley experiment) % Ca

Barley plants	0.45, 0.51, 0.45, 0.45, 0.47, 0.49, 0.49, 0.51, 0.49, 0.49

† Mean of 2 determinations.

Table 19. Mg - error in plant analysis

Recovery 1 mg Mg (≙ 0.2%) added to 0.5 g sample of plant material

Plant Material	% Mg†		% Recovery
	Plant Mg	Plant + added Mg	
Maize plants	.141	.342	100.5
Grass	.134	.338	102.0
Clover	.470	.669	99.5
Turnip	.095	.294	99.5
Sugar beet tops	.288	.488	100.0
Sugar beet leaves	.528	.731	101.5
Potato foliage	.883	1.083	100.0
Barley grains	.118	.314	98.0
Beans	.119	.321	101.0
Marrowstem kale	.181	.383	101.0

Replicate analysis % Mg

Oat plants	.135,	.136,	.137,	.138,	.139,	.140,	.140,	.144,	.146,	.150
Rape	.181,	.182,	.186,	.186,	.187,	.187,	.187,	.189,	.192,	.197

Sampling error (barley experiment) % Mg

Barley plants	.087,	.081,	.089,	.087,	.081,	.092,	.088,	.092,	.089,	.087

†Mean of 2 determinations.

Table 20. P - error in plant analysis

Plant Material	% P†		% Recovery
	Plant P	Plant + added P	
Recovery	1 mg P (≙ 0.2%) added to 0.5 g sample of plant material		
Maize plants	.247	.445	99.0
Grass	.256	.453	98.5
Clover	.278	.482	102.0
Turnip	.418	.621	101.5
Sugar beet tops	.285	.490	102.5
Sugar beet leaves	.219	.418	99.5
Potato foliage	.135	.338	101.5
Barley grains	.346	.547	100.5
Beans	.527	.730	101.5
Marrowstem kale	.255	.454	99.5

Replicate analysis % P

Oat plants	.085,	.088,	.088,	.089,	.090,	.090,	.090,	.090,	.093,	.093
Rape	.312,	.312,	.313,	.315,	.315,	.316,	.316,	.317,	.318,	.319

Sampling error (barley experiment) % P

Barley plants	.260,	.273,	.255,	.256,	.261,	.256,	.258,	.263,	.266,	.262

† Mean of 2 determinations.

Table 21. N - error in plant analysis.

Comparison of proposed method with A.O.A.C. method. % N					
Grass sample (1)	Proposed method	3.15	3.14	3.16	3.12
	A.O.A.C. method	3.15	3.14	3.16	3.15
Grass sample (2)	Proposed method	2.49	2.49	2.51	2.47
	A.O.A.C. method	2.49	2.50	2.50	2.49

Replicate analysis using proposed method. % N

Oats	3.74, 3.80, 3.76, 3.68, 3.72, 3.66, 3.76, 3.78, 3.76, 3.62
Rape	2.08, 2.05, 2.04, 2.05, 2.07, 2.05, 2.07, 2.07, 2.04, 2.08

Table 22. Effect of carbon on the determination of NH_4-N in soil

	ppm NH_4-N in oven-dry soil
With carbon	8.3, 8.2, 8.5, 8.5, 8.1, 8.3, 8.3, 8.2, 8.2, 8.3
Without carbon	7.8, 8.1, 8.1, 7.8, 7.9, 8.0, 8.0, 8.2, 8.2, 8.1

Table 23. Results of standardisation of methods of soil analysis.

pH		mg/100 g soil						ppm in oven-dry soil			
		P		K		Mg		NO_3-N		NH_4-N	
S	A	S	A	S	A	S	A	S	A	S	A
5.5	6.0	.43	.40	8.7	11.0	6.2	7.6	1.7	5.6	2.4	6.5
5.7	6.0	.53	.38	11.0	10.3	6.5	7.3	4.2	5.5	3.1	6.9
5.8	6.1	.43	.35	10.7	10.7	7.6	6.8	2.2	4.8	2.3	6.6
6.0	6.1	.48	.35	11.7	11.4	8.7	6.8	4.5	4.9	4.7	6.6
5.9	5.9	.40	.35	12.5	11.0	7.3	7.4	3.0	4.4	4.2	6.5
5.8	6.0	.40	.35	10.0	11.0	7.6	7.2	5.0	5.0	2.9	6.7
5.7	6.0	.48	.35	12.1	11.0	8.7	7.6	4.3	5.8	3.1	6.4
5.7	6.1	.38	.33	9.0	10.7	7.6	7.4	3.7	5.5	4.4	6.6
6.0	6.0	.48	.38	12.1	10.3	6.2	7.5	4.2	5.2	6.3	6.6
5.9	6.1	.45	.35	10.7	10.7	9.2	7.5	2.6	4.8	2.4	7.0

S = sampling error determinations A = analytical error determinations

APPENDIX II. Results of Barley Experiment (1962).

Table 24. Layout of the barley experiment (1962).

	Treatment					
	CaNT	CaNT	CaNT	CaNT	CaNT	CaNT
	Block a		Block b		Block c	
Replicate 1	101	110	200	111	121	011
	211	000	010	001	210	020
	220	021	120	221	100	201
Replicate 3	111	021	020	110	210	101
	100	220	200	001	011	221
	010	201	211	121	120	000
Replicate 2	121	000	111	001	211	021
	220	110	221	210	010	101
	201	011	020	100	120	200
Replicate 4	020	200	021	210	220	010
	101	221	111	000	001	100
	011	110	120	201	121	211

$T_0 = (NH_4)_2SO_4$ $T_1 = NaNO_3$

(The experimental design and analysis of variance are described in detail in "Experimental Designs" by Cochran, W. G. and Cox, G. M. 1950 Wiley, New York. pp 174-183.)

Table 25. Monthly weather data for the barley experiment. The observations were made at Turnhouse, about 3 miles to the north-west of the experimental site.

1962	Rainfall (in.)	Mean Temperatures (°F)	
		Maximum	Minimum
January	2.42	43.2	33.6
February	1.29	44.8	34.5
March	0.59	43.0	29.8
April	2.10	51.8	36.5
May	1.05	56.7	41.7
June	0.47	64.8	46.0
July	3.52	62.6	48.9
August	3.89	62.1	48.7
September	4.22	58.6	46.9

Table 26. Effect of treatments on the growth of barley: an estimate from visual observations taken on 22 June 1962.

Treatment CaNT	Replicate No.1	No.2	No.3	No.4
000	1	1	1	1
001	1	1	1	1
010	2	3	1	3
011	3	4	3	2
020	3	3	3	4
021	4	4	4	4
100	1	1	1	1
101	2	2	1	1
110	3	3	2	2
111	3	3	3	3
120	4	4	4	4
121	4	4	4	4
200	2	2	1	3
201	1	3	1	2
210	3	2	3	4
211	3	4	3	2
220	3	4	3	4
221	4	4	4	4

Scale: 1 (poor growth) - 4 (good growth)

Table 27. Barley experiment (1962): % dry matter in barley.

Treatment CaNT	3-4 leaf stage				5-6 leaf stage				before "heading"				after "heading"				Treatment CaNT
	1†	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
000	16.7	15.9	16.0	17.1	23.2	18.2	17.6	19.5	25.8	24.8	24.6	24.2	31.9	31.1	31.1	30.4	000
001	16.0	16.3	16.3	16.2	19.7	18.2	18.8	20.3	24.2	22.7	23.5	27.5	30.9	29.2	30.1	31.0	001
010	15.7	15.5	16.1	16.3	18.9	17.9	18.0	17.6	25.3	24.6	24.4	24.2	33.7	30.3	30.2	32.2	010
011	14.6	13.2	15.0	15.9	17.8	16.5	18.4	19.5	24.6	23.1	25.0	25.1	31.4	30.2	30.6	31.6	011
020	14.7	15.5	16.7	15.7	17.5	16.8	16.6	17.4	25.1	23.8	24.1	23.8	31.8	30.1	31.1	29.3	020
021	13.6	14.2	15.0	14.4	17.0	16.5	16.5	16.0	24.5	24.6	23.6	24.3	30.9	31.8	30.1	31.6	021
100	15.8	16.2	16.4	16.7	19.7	18.4	19.4	18.7	25.0	23.3	25.3	24.3	31.0	29.8	30.0	30.4	100
101	15.2	15.2	15.4	17.1	18.3	17.6	18.5	19.1	25.4	24.2	23.9	24.3	31.6	31.1	30.9	30.6	101
110	14.4	15.0	15.3	15.6	18.6	17.2	18.1	19.5	24.8	23.2	23.7	24.9	32.6	30.2	30.2	31.7	110
111	14.9	14.8	15.2	15.0	18.2	16.5	17.7	17.2	24.4	23.3	24.4	23.9	32.1	30.7	31.6	31.0	111
120	15.2	16.4	14.4	15.8	16.3	17.9	17.6	17.7	23.6	25.0	24.5	25.1	30.5	31.3	30.8	32.3	120
121	13.8	14.0	13.8	15.7	18.7	16.4	16.5	18.3	22.9	22.5	22.3	24.4	30.5	29.9	29.1	30.5	121
200	15.4	16.5	15.8	16.1	18.2	18.2	18.1	18.6	24.6	24.2	24.8	24.6	31.4	32.0	32.1	30.6	200
201	16.2	16.2	15.9	19.6	19.0	18.6	18.9	19.3	25.3	23.9	25.1	24.6	30.6	30.2	31.0	30.3	201
210	17.0	13.2	15.0	15.2	14.8	17.5	18.1	18.5	24.7	23.2	25.0	23.7	30.5	29.3	30.3	30.7	210
211	14.5	14.8	14.8	15.5	17.9	17.6	16.4	19.5	26.1	25.1	23.9	26.5	32.4	29.9	31.3	33.0	211
220	15.7	14.4	15.0	16.1	18.3	17.6	17.7	18.3	24.3	24.0	24.8	24.7	30.8	29.9	31.9	31.7	220
221	14.4	14.8	17.0	14.1	17.4	15.3	16.0	16.8	22.0	22.8	25.2	21.8	30.0	29.0	30.0	28.9	221

† These figures denote the replicates.

Table 28. Barley experiment (1962): % Mg content of barley.

Treatment CaNT	3-4 leaf stage				5-6 leaf stage				before "heading"				Treatment CaNT
	1†	2	3	4	1	2	3	4	1	2	3	4	
000	.113	.138	.131	.139	.092	.105	.100	.094	.081	.090	.090	.104	000
001	.131	.147	.136	.141	.089	.092	.094	.090	.092	.099	.102	.090	001
010	.123	.140	.145	.153	.101	.097	.113	.116	.096	.099	.101	.104	010
011	.134	.136	.128	.116	.100	.124	.094	.101	.095	.100	.100	.085	011
020	.157	.168	.139	.140	.114	.128	.116	.116	.106	.097	.106	.113	020
021	.138	.142	.131	.150	.105	.114	.105	.122	.095	.092	.099	.099	021
100	.123	.145	.146	.142	.086	.096	.109	.106	.088	.105	.097	.092	100
101	.120	.136	.137	.123	.100	.103	.104	.103	.087	.092	.090	.075	101
110	.139	.147	.151	.145	.102	.115	.100	.115	.114	.110	.107	.106	110
111	.123	.152	.147	.153	.091	.113	.110	.112	.100	.099	.107	.096	111
120	.139	.159	.149	.166	.119	.119	.105	.132	.113	.111	.113	.097	120
121	.118	.142	.147	.129	.100	.120	.109	.097	.107	.115	.115	.110	121
200	.121	.155	.166	.136	.100	.109	.104	.110	.088	.105	.090	.097	200
201	.135	.144	.135	.137	.099	.098	.103	.096	.084	.106	.086	.105	201
210	.153	.162	.144	.151	.107	.109	.101	.102	.105	.104	.105	.093	210
211	.134	.151	.145	.115	.115	.101	.112	.101	.095	.107	.093	.096	211
220	.163	.163	.151	.133	.121	.122	.120	.111	.100	.122	.102	.116	220
221	.135	.141	.144	.135	.100	.124	.119	.120	.108	.099	.100	.116	221

† These figures denote the replicates.

Table 28, (contd.). Barley experiment (1962): % Mg content of barley.

Treatment CaNT	after "heading"				maturity - straw				maturity - grain				Treatment CaNT
	1†	2	3	4	1	2	3	4	1	2	3	4	
000	.088	.080	.079	.095	.050	.050	.053	.048	.114	.110	.105	.111	000
001	.094	.071	.078	.081	.050	.048	.048	.046	.119	.115	.119	.115	001
010	.084	.089	.088	.090	.047	.051	.050	.055	.106	.116	.110	.108	010
011	.087	.095	.091	.086	.054	.051	.055	.048	.111	.111	.116	.101	011
020	.096	.093	.094	.100	.050	.043	.043	.049	.115	.109	.113	.111	020
021	.088	.092	.096	.088	.050	.053	.051	.043	.118	.108	.116	.116	021
100	.089	.083	.087	.082	.054	.053	.048	.051	.111	.115	.111	.106	100
101	.097	.087	.080	.076	.055	.057	.050	.048	.111	.116	.109	.111	101
110	.088	.082	.093	.093	.047	.050	.048	.049	.114	.111	.118	.105	110
111	.095	.084	.091	.091	.052	.044	.054	.044	.120	.116	.117‡	.111	111
120	.086	.098	.104	.103	.046	.054	.054	.050	.108	.112	.121	.113	120
121	.090	.088	.091	.096	.050	.053	.059	.049	.113	.112	.122	.114	121
200	.079	.086	.096	.088	.054	.055	.047	.054	.113	.111	.118	.109	200
201	.090	.082	.084	.088	.052	.050	.050	.054	.112‡	.105	.116	.115	201
210	.096	.088	.095	.104	.049	.049	.049	.052	.113	.115	.111	.112	210
211	.092	.094	.088	.098	.055	.051	.048	.049	.107	.117	.113	.110	211
220	.101	.100	.098	.103	.050	.055	.057	.052	.111	.115	.110	.111	220
221	.096	.085	.091	.098	.048	.048	.053	.050	.116	.113	.107	.110	221

† These figures denote the replicates.

‡ Estimated values for missing data.

Table 29. Barley experiment (1962): % Ca content of barley.

Treatment CaNT	3-4 leaf stage				5-6 leaf stage				before "heading"				Treatment CaNT
	†1	2	3	4	1	2	3	4	1	2	3	4	
000	0.67	0.81	0.91	0.87	0.41	0.46	0.58	0.52	0.23	0.27	0.32	0.34	000
001	0.80	0.88	0.87	0.82	0.44	0.50	0.50	0.44	0.31	0.38	0.35	0.29	001
010	0.84	0.99	0.90	0.91	0.49	0.54	0.54	0.58	0.29	0.30	0.29	0.41	010
011	0.70	0.74	0.76	0.72	0.42	0.49	0.44	0.41	0.29	0.32	0.29	0.29	011
020	0.96	1.00	0.87	0.93	0.53	0.65	0.59	0.51	0.30	0.36	0.33	0.33	020
021	0.64	0.78	0.64	0.63	0.39	0.53	0.42	0.51	0.27	0.31	0.31	0.32	021
100	0.81	0.96	0.86	0.93	0.40	0.57	0.52	0.58	0.24	0.36	0.30	0.35	100
101	0.79	0.90	0.89	0.77	0.46	0.55	0.50	0.55	0.30	0.37	0.27	0.30	101
110	0.90	0.99	1.02	1.06	0.49	0.53	0.51	0.57	0.32	0.35	0.36	0.34	110
111	0.73	0.82	0.75	0.77	0.44	0.52	0.47	0.51	0.33	0.31	0.32	0.32	111
120	0.96	1.25	1.21	1.14	0.58	0.64	0.59	0.70	0.35	0.37	0.34	0.33	120
121	0.68	0.78	0.79	0.69	0.46	0.50	0.46	0.41	0.32	0.32	0.38	0.31	121
200	0.83	0.98	1.04	0.81	0.48	0.61	0.55	0.52	0.31	0.38	0.29	0.28	200
201	0.80	0.88	0.85	0.93	0.49	0.56	0.50	0.51	0.27	0.33	0.27	0.35	201
210	0.91	1.08	1.02	0.99	0.43	0.54	0.49	0.53	0.30	0.34	0.32	0.35	210
211	0.73	0.91	0.79	0.76	0.47	0.48	0.55	0.48	0.27	0.31	0.32	0.38	211
220	1.11	1.18	1.02	1.17	0.57	0.62	0.54	0.62	0.31	0.38	0.33	0.36	220
221	0.72	0.75	0.82	0.76	0.42	0.55	0.48	0.48	0.35	0.33	0.30	0.34	221

† These figures denote the replicates.

Table 29, (contd.). Barley experiment (1962). % Ca content of barley.

Treatment CaNT	after "heading"				maturity - straw				maturity - grain				Treatment CaNT
	1†	2	3	4	1	2	3	4	1	2	3	4	
000	0.23	0.25	0.28	0.26	0.18	0.21	0.22	0.18	0.07	0.04	0.06	0.06	000
001	0.25	0.27	0.25	0.26	0.21	0.19	0.19	0.19	0.05	0.06	0.05	0.06	001
010	0.25	0.30	0.25	0.28	0.20	0.21	0.20	0.20	0.06	0.05	0.06	0.05	010
011	0.33	0.30	0.27	0.26	0.18	0.20	0.23	0.18	0.05	0.05	0.05	0.05	011
020	0.30	0.33	0.29	0.31	0.19	0.19	0.19	0.19	0.06	0.05	0.05	0.05	020
021	0.26	0.25	0.26	0.29	0.20	0.21	0.19	0.18	0.05	0.05	0.06	0.05	021
100	0.26	0.28	0.26	0.25	0.23	0.20	0.20	0.21	0.04	0.06	0.05	0.05	100
101	0.27	0.27	0.28	0.27	0.20	0.21	0.21	0.20	0.05	0.05	0.05	0.05	101
110	0.28	0.29	0.28	0.25	0.20	0.22	0.19	0.20	0.05	0.05	0.05	0.05	110
111	0.27	0.27	0.24	0.26	0.19	0.19	0.19	0.19	0.05	0.06	0.06‡	0.05	111
120	0.29	0.33	0.34	0.33	0.18	0.21	0.23	0.20	0.05	0.05	0.05	0.06	120
121	0.28	0.24	0.27	0.26	0.20	0.19	0.22	0.18	0.04	0.05	0.05	0.04	121
200	0.28	0.26	0.28	0.25	0.19	0.23	0.19	0.21	0.05	0.04	0.05	0.05	200
201	0.28	0.28	0.27	0.24	0.21	0.21	0.22	0.19	0.04‡	0.05	0.05	0.05	201
210	0.28	0.30	0.29	0.32	0.20	0.20	0.24	0.20	0.05	0.05	0.05	0.06	210
211	0.25	0.28	0.27	0.25	0.20	0.19	0.19	0.21	0.05	0.06	0.06	0.05	211
220	0.32	0.33	0.32	0.33	0.22	0.21	0.23	0.19	0.06	0.05	0.05	0.06	220
221	0.25	0.28	0.29	0.26	0.19	0.19	0.20	0.20	0.04	0.05	0.05	0.05	221

† These figures denote the replicates.

‡ Estimated values for missing data.

Table 30. Barley experiment (1962): % K content of barley.

Treatment CaNT	3-4 leaf stage				5-6 leaf stage				before "heading"				Treatment CaNT
	1†	2	3	4	1	2	3	4	1	2	3	4	
000	2.80	3.05	3.12	2.34	2.62	2.86	2.92	2.32	1.78	1.77	1.84	1.54	000
001	2.84	2.72	2.80	2.40	2.52	2.92	2.80	2.52	1.73	1.87	1.78	1.69	001
010	2.74	2.60	2.86	3.02	2.16	2.60	2.54	2.34	1.57	1.59	1.68	1.49	010
011	2.99	2.72	2.50	2.26	2.34	2.32	2.56	2.10	1.60	1.49	1.61	1.22	011
020	3.12	2.66	2.66	2.84	2.42	2.10	2.46	2.58	1.38	1.49	1.49	1.47	020
021	2.90	3.12	2.77	2.60	2.32	2.42	2.48	2.00	1.38	1.47	1.54	1.19	021
100	2.84	2.46	2.86	2.70	2.74	2.72	2.66	2.60	1.77	1.63	1.84	1.76	100
101	3.02	3.48	3.07	2.38	2.54	2.94	2.79	2.60	1.81	1.86	1.76	1.82	101
110	3.12	3.28	2.92	2.52	2.48	2.70	2.58	2.00	1.57	1.74	1.50	1.20	110
111	2.58	2.64	2.70	2.28	2.38	2.42	2.34	2.22	1.36	1.62	1.56	1.41	111
120	2.72	2.15	2.77	2.60	2.20	2.22	2.50	1.90	1.37	1.48	1.65	1.19	120
121	2.01	2.92	2.61	2.30	2.46	2.38	2.52	2.14	1.59	1.49	1.55	1.37	121
200	2.76	2.92	2.68	3.05	2.64	2.56	2.64	2.46	1.60	1.63	1.67	1.65	200
201	2.99	2.72	2.84	2.40	2.74	2.58	2.82	2.46	1.83	1.67	1.78	1.47	201
210	2.74	2.55	3.05	2.70	2.35	2.54	2.70	2.17	1.67	1.46	1.71	1.36	210
211	2.90	2.22	2.52	2.36	2.40	2.52	2.46	2.10	1.45	1.49	1.52	1.37	211
220	2.75	2.84	3.08	2.42	2.22	2.38	2.50	2.08	1.50	1.58	1.68	1.37	220
221	2.64	2.16	2.85	2.40	2.30	2.38	2.34	1.92	1.40	1.35	1.42	1.40	221

† These figures denote the replicates.

Table 30, (contd.). Barley experiment (1962): % K content of barley.

Treatment CaNT	after "heading"				maturity - straw				maturity - grain				Treatment CaNT
	1†	2	3	4	1	2	3	4	1	2	3	4	
000	1.19	1.20	1.21	1.08	0.47	0.50	0.42	0.44	0.46	0.41	0.41	0.43	000
001	1.18	1.25	1.23	1.16	0.51	0.66	0.57	0.45	0.45	0.43	0.43	0.43	001
010	0.92	1.12	1.08	1.01	0.28	0.59	0.45	0.29	0.39	0.43	0.41	0.38	010
011	1.01	0.98	1.03	0.98	0.27	0.41	0.48	0.29	0.41	0.39	0.41	0.40	011
020	0.91	0.89	0.97	1.07	0.40	0.66	0.50	0.65	0.40	0.40	0.40	0.39	020
021	0.95	1.08	1.01	0.79	0.31	0.39	0.31	0.40	0.40	0.39	0.40	0.40	021
100	1.23	1.11	1.35	1.28	0.57	0.63	0.43	0.51	0.45	0.43	0.44	0.43	100
101	1.25	1.27	1.21	1.25	0.28	0.48	0.44	0.41	0.41	0.42	0.43	0.45	101
110	1.11	1.18	1.06	0.98	0.28	0.52	0.61	0.43	0.41	0.40	0.40	0.42	110
111	1.06	0.96	0.94	0.86	0.39	0.49	0.23	0.27	0.39	0.40	0.41‡	0.41	111
120	0.92	1.02	1.08	0.84	0.45	0.57	0.68	0.66	0.40	0.39	0.40	0.43	120
121	0.95	1.00	1.05	0.95	0.36	0.40	0.59	0.39	0.38	0.44	0.41	0.40	121
200	1.21	1.16	1.08	1.19	0.48	0.40	0.54	0.43	0.41	0.41	0.45	0.41	200
201	1.27	1.16	1.21	1.13	0.42	0.39	0.55	0.57	0.43‡	0.37	0.45	0.45	201
210	1.08	1.10	1.14	0.91	0.48	0.65	0.59	0.55	0.41	0.41	0.41	0.38	210
211	0.99	1.12	1.05	0.97	0.23	0.46	0.50	0.29	0.41	0.40	0.42	0.40	211
220	0.97	1.04	1.00	0.91	0.43	0.41	0.55	0.59	0.40	0.39	0.40	0.39	220
221	0.93	0.96	0.96	0.95	0.49	0.49	0.31	0.33	0.40	0.41	0.36	0.39	221

† These figures denote the replicates.

‡ Estimated values for missing data.

Table 31. Barley experiment (1962): % Na content of barley.

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				Treatment
CaNT	1†	2	3	4	1	2	3	4	1	2	3	4	CaNT
000	.336	.396	.383	.516	.128	.152	.198	.223	.094	.206	.124	.202	000
001	.366	.421	.383	.413	.162	.210	.176	.150	.142	.207	.176	.129	001
010	.318	.458	.401	.343	.235	.203	.230	.316	.167	.179	.190	.257	010
011	.661	1.165	.731	.698	.341	.521	.309	.340	.212	.300	.246	.293	011
020	.426	.411	.413	.331	.294	.396	.303	.240	.231	.246	.218	.242	020
021	.996	.800	.907	.955	.494	.556	.476	.690	.359	.332	.338	.392	021
100	.401	.426	.363	.431	.157	.198	.159	.200	.129	.234	.114	.144	100
101	.368	.333	.456	.378	.150	.172	.205	.205	.105	.134	.122	.121	101
110	.393	.398	.380	.383	.182	.205	.223	.230	.179	.350	.246	.249	110
111	.678	.826	.764	.924	.296	.443	.434	.456	.312	.281	.293	.298	111
120	.448	.405	.436	.398	.363	.271	.246	.346	.268	.222	.212	.253	120
121	.742	.937	1.128	.958	.185	.581	.554	.498	.331	.405	.454	.401	121
200	.461	.461	.414	.388	.185	.258	.196	.215	.139	.206	.136	.169	200
201	.421	.446	.475	.472	.187	.225	.160	.235	.095	.198	.137	.222	201
210	.329	.539	.294	.514	.499	.289	.192	.289	.173	.287	.181	.268	210
211	.769	1.000	.828	.758	.351	.390	.485	.366	.249	.297	.268	.273	211
220	.381	.458	.293	.376	.240	.266	.205	.258	.238	.211	.198	.227	220
221	.889	1.171	.990	1.133	.474	.636	.594	.602	.463	.402	.335	.462	221

† These figures denote the replicates.

Table 31 (contd.). Barley experiment (1962): % Na content of barley.

Treatment	after "heading"				maturity - straw				maturity - grain				Treatment
CaNT	1†	2	3	4	1	2	3	4	1	2	3	4	CaNT
000	.103	.123	.122	.156	.055	.073	.058	.084	.014	.012	.013	.013	000
001	.110	.149	.118	.115	.061	.090	.089	.065	.012	.011	.012	.013	001
010	.151	.167	.194	.171	.049	.105	.084	.057	.013	.014	.014	.012	010
011	.226	.317	.253	.236	.075	.127	.117	.067	.015	.018	.015	.015	011
020	.191	.228	.196	.214	.077	.176	.103	.122	.015	.013	.012	.018	020
021	.315	.251	.313	.363	.103	.099	.142	.193	.017	.014	.020	.019	021
100	.120	.172	.099	.105	.084	.109	.053	.059	.012	.014	.012	.011	100
101	.097	.087	.120	.110	.037	.054	.053	.049	.012	.013	.013	.013	101
110	.127	.137	.189	.177	.048	.078	.104	.083	.014	.013	.011	.015	110
111	.198	.267	.272	.268	.094	.128	.075	.087	.012	.016	.016‡	.016	111
120	.228	.178	.213	.218	.111	.124	.124	.117	.013	.016	.013	.015	120
121	.350	.312	.335	.329	.163	.192	.217	.153	.016	.016	.015	.019	121
200	.098	.132	.127	.142	.064	.065	.068	.073	.011	.013	.013	.015	200
201	.109	.157	.134	.156	.047	.063	.083	.095	.015‡	.015	.016	.014	201
210	.171	.191	.169	.233	.094	.143	.091	.134	.013	.014	.012	.013	210
211	.251	.258	.227	.221	.065	.136	.111	.083	.018	.016	.015	.015	211
220	.188	.204	.167	.212	.082	.083	.074	.128	.016	.012	.015	.013	220
221	.343	.327	.345	.332	.188	.170	.115	.189	.015	.015	.017	.019	221

† These figures denote the replicates.

‡ Estimated values for missing data.

Table 32. Barley experiment (1962): % P content of barley.

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				Treatment
CaNT	1†	2	3	4	1	2	3	4	1	2	3	4	CaNT
000	.381	.386	.360	.370	.285	.315	.301	.300	.246	.236	.239	.231	000
001	.384	.393	.401	.348	.299	.303	.303	.299	.236	.227	.223	.259	001
010	.385	.404	.381	.372	.270	.303	.289	.284	.227	.237	.214	.200	010
011	.351	.381	.386	.316	.271	.300	.302	.267	.211	.211	.227	.187	011
020	.406	.352	.391	.350	.284	.281	.298	.291	.219	.207	.204	.200	020
021	.391	.370	.360	.351	.299	.281	.282	.270	.200	.175	.219	.192	021
100	.391	.389	.388	.382	.301	.307	.287	.298	.254	.226	.249	.228	100
101	.370	.403	.401	.349	.286	.307	.316	.280	.230	.224	.248	.247	101
110	.412	.404	.409	.388	.284	.306	.310	.268	.237	.227	.209	.190	110
111	.375	.388	.379	.370	.292	.278	.284	.268	.207	.208	.225	.218	111
120	.389	.384	.404	.400	.285	.298	.313	.268	.202	.213	.217	.201	120
121	.389	.404	.419	.382	.302	.282	.305	.284	.235	.212	.202	.229	121
200	.383	.373	.383	.372	.293	.310	.303	.301	.202	.221	.245	.239	200
201	.388	.372	.391	.386	.301	.298	.318	.309	.252	.228	.249	.227	201
210	.400	.438	.424	.405	.300	.307	.316	.297	.237	.202	.236	.193	210
211	.366	.406	.386	.350	.281	.310	.287	.272	.220	.210	.212	.208	211
220	.383	.421	.403	.403	.271	.299	.301	.290	.209	.211	.216	.205	220
221	.398	.377	.358	.372	.286	.281	.287	.284	.202	.203	.203	.233	221

† These figures denote the replicates.

Table 32 (contd.). Barley experiment (1962): % P content of barley.

Treatment	after "heading"				maturity - straw				maturity - grain				Treatment
CaNT	1†	2	3	4	1	2	3	4	1	2	3	4	CaNT
000	.204	.197	.174	.200	.075	.059	.074	.058	.356	.348	.330	.345	000
001	.196	.185	.185	.202	.062	.072	.058	.067	.367	.355	.362	.348	001
010	.157	.174	.175	.164	.050	.065	.072	.064	.319	.345	.340	.293	010
011	.151	.167	.164	.176	.064	.058	.058	.064	.327	.308	.335	.308	011
020	.148	.149	.158	.163	.059	.058	.053	.063	.335	.326	.345	.326	020
021	.150	.150	.175	.147	.056	.065	.051	.055	.307	.316	.325	.324	021
100	.193	.173	.201	.211	.069	.067	.058	.065	.367	.354	.354	.346	100
101	.208	.191	.180	.211	.065	.072	.074	.066	.337	.354	.361	.380	101
110	.183	.183	.175	.184	.051	.063	.065	.061	.336	.335	.356	.328	110
111	.191	.158	.164	.158	.058	.056	.058	.052	.335	.349	.349‡	.327	111
120	.157	.151	.158	.163	.052	.074	.074	.071	.324	.313	.339	.345	120
121	.168	.150	.158	.158	.059	.073	.073	.057	.312	.355	.340	.322	121
200	.177	.195	.182	.191	.063	.061	.066	.071	.344	.354	.364	.344	200
201	.194	.181	.196	.205	.071	.058	.072	.074	.354‡	.304	.381	.366	201
210	.175	.165	.170	.155	.059	.064	.058	.057	.344	.341	.344	.317	210
211	.160	.162	.160	.175	.052	.051	.058	.058	.326	.328	.347	.315	211
220	.159	.173	.152	.146	.065	.057	.074	.067	.334	.327	.327	.314	220
221	.152	.157	.142	.179	.059	.054	.059	.052	.328	.345	.296	.326	221

† These figures denote the replicates.

‡ Estimated values for missing data.

Table 33. Barley experiment: initial soil analysis (18 Dec. 1961).

Treatment CaNT	pH				"Available" nutrients (mg/100 g soil)												Treatment CaNT
					P				K				Mg				
	1†	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
000	5.7	5.5	5.3	5.4	.23	.25	.50	.25	6.1	5.5	6.7	3.3	7.5	7.9	5.8	6.7	000
001	5.6	5.5	5.5	5.4	.35	.35	.38	.30	4.0	5.0	4.7	3.7	7.6	6.3	5.9	5.1	001
010	5.6	5.5	5.5	5.4	.30	.43	.33	.38	5.5	5.3	4.7	3.5	5.3	6.9	7.6	5.8	010
011	5.5	5.5	5.4	5.4	.40	.23	.43	.25	5.8	5.8	5.8	3.7	6.6	6.6	6.1	6.1	011
020	5.5	5.4	5.4	5.5	.45	.33	.33	.28	6.1	4.0	6.1	4.3	5.4	6.3	5.9	6.3	020
021	5.6	5.2	5.6	5.3	.28	.45	.28	.28	6.4	6.1	9.3	4.3	7.8	5.2	7.2	6.3	021
100	5.6	5.3	5.4	5.3	.38	.40	.30	.30	5.0	3.7	5.0	6.4	8.6	7.5	7.6	5.8	100
101	5.4	5.5	5.4	5.7	.30	.43	.48	.23	3.7	6.7	6.1	3.7	7.0	5.1	5.2	6.6	101
110	5.7	5.7	5.5	5.5	.23	.28	.38	.20	6.1	6.4	5.0	3.7	7.3	7.2	7.9	7.2	110
111	5.5	5.4	5.6	5.4	.40	.38	.40	.23	4.3	5.8	5.8	3.7	6.1	6.3	7.2	7.6	111
120	5.5	5.6	5.4	5.4	.30	.40	.45	.28	5.8	4.0	5.8	4.7	5.3	5.8	7.0	7.3	120
121	5.5	5.4	5.4	5.4	.45	.33	.40	.35	5.5	4.7	4.7	4.3	8.0	6.3	7.9	5.3	121
200	5.6	5.4	5.4	5.5	.33	.38	.33	.20	5.3	4.3	5.5	5.0	5.6	4.6	5.4	7.8	200
201	5.7	5.5	5.2	5.5	.38	.30	.28	.30	5.3	3.5	6.4	3.3	5.8	6.3	6.9	6.9	201
210	5.7	5.5	5.6	5.3	.35	.35	.43	.33	4.7	3.5	4.7	3.0	9.4	7.8	8.6	6.3	210
211	5.7	5.5	5.5	5.2	.28	.38	.35	.33	3.3	5.5	5.8	6.1	6.1	6.6	5.4	4.8	211
220	5.6	5.4	5.5	5.4	.28	.40	.25	.43	4.3	5.0	7.0	4.0	6.9	6.5	6.9	6.3	220
221	5.5	5.4	5.4	5.6	.35	.33	.45	.15	5.5	5.3	6.4	4.0	6.6	5.8	5.8	6.9	221

† These figures denote the replicates.

Table 34. Barley experiment: final soil analysis (26 Sept. 1962).

Treatment CaNT	pH				"Available" nutrients (mg/100 g soil)												Treatment CaNT
					P				K				Mg				
	1†	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
000	5.8	5.5	5.5	5.5	.30	.33	.36	.24	5.0	5.6	5.4	3.0	6.5	6.5	5.5	5.7	000
001	5.6	5.5	5.5	5.6	.36	.36	.34	.31	4.2	4.9	4.9	6.9	5.6	6.0	6.1	5.6	001
010	5.7	5.9	5.3	5.5	.31	.41	.31	.33	5.3	6.0	5.6	5.1	5.6	7.7	6.3	4.0	010
011	5.7	5.5	5.5	5.5	.35	.33	.45	.25	4.5	4.8	7.0	5.8	5.6	6.2	4.3	4.5	011
020	5.8	5.3	5.5	5.3	.35	.31	.25	.22	5.0	4.2	5.3	4.8	6.4	4.4	5.5	5.4	020
021	5.7	5.7	5.5	5.6	.26	.39	.28	.25	4.7	5.2	4.6	3.8	6.3	5.0	5.9	5.0	021
100	6.3	5.7	5.9	6.1	.42	.34	.39	.30	5.3	3.3	5.2	4.3	6.1	6.1	7.3	4.7	100
101	6.1	5.7	5.7	5.9	.36	.41	.40	.22	7.5	6.5	4.4	4.3	7.4	4.5	5.6	5.8	101
110	5.8	5.7	5.7	5.6	.35	.33	.35	.32	5.1	5.1	4.0	4.3	6.4	6.4	5.6	5.6	110
111	6.0	5.8	5.6	5.9	.39	.35	.32	.24	4.1	4.8	5.3	4.3	6.4	5.5	6.7	4.6	111
120	5.8	5.9	5.9	5.7	.28	.42	.41	.28	5.3	5.5	5.0	4.3	5.7	5.8	4.7	6.4	120
121	5.9	6.0	5.7	6.0	.36	.53	.37	.29	5.2	8.4	5.0	5.7	5.6	6.4	5.9	6.1	121
200	6.1	6.1	5.9	6.1	.31	.37	.32	.30	5.1	4.1	4.2	4.1	6.1	4.7	5.6	6.4	200
201	6.1	5.9	6.1	5.9	.39	.33	.33	.31	4.1	5.0	4.9	3.7	5.7	7.0	6.1	5.7	201
210	6.0	5.9	6.0	5.7	.39	.29	.38	.29	5.4	4.2	5.8	3.3	5.1	6.7	6.4	6.0	210
211	6.1	6.0	6.3	6.3	.35	.39	.37	.36	6.4	4.6	5.0	4.6	6.4	5.0	5.7	4.6	211
220	6.0	5.9	5.9	6.0	.44	.32	.31	.44	5.6	4.8	4.2	5.2	6.4	6.6	6.1	5.3	220
221	6.0	6.2	5.7	6.3	.33	.33	.41	.25	4.1	4.6	4.4	4.1	6.1	5.8	5.7	6.6	221

† These figures denote the replicates.

Table 35. Barley experiment (1962): soil mineral N content (ppm N in oven-dry soil).

Treatment CaNT	14 May		28 May		14 June		28 June		26 Sept.		Treatment CaNT
	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	
000	3.4	7.7	4.2	3.8	1.9	2.0	3.2	1.4	2.7	1.5	000
001	3.0	7.7	2.9	5.8	2.6	0.7	3.1	1.7	3.2	2.1	001
010	4.8	14.8	3.3	14.3	3.7	10.2	5.6	6.3	3.3	1.3	010
011	4.9	15.4	2.4	4.7	2.9	4.7	3.3	2.3	2.3	2.4	011
020	18.9	26.6	8.7	18.4	6.3	7.4	7.1	6.7	2.6	1.9	020
021	5.0	27.2	2.1	16.5	2.6	4.7	4.6	4.1	2.6	2.3	021
100	4.3	7.3	2.5	5.6	2.9	3.5	3.9	2.1	3.2	2.4	100
101	4.4	5.0	2.3	5.2	1.8	3.0	3.6	2.3	1.9	1.9	101
110	6.6	20.8	3.0	13.9	2.4	5.1	4.2	5.4	2.6	2.0	110
111	4.1	15.9	2.0	7.3	2.4	3.8	3.4	3.5	2.5	1.3	111
120	9.8	27.8	4.4	17.7	3.7	13.9	4.3	4.9	2.4	1.6	120
121	4.2	25.8	2.0	16.8	3.4	7.0	3.0	4.8	2.3	2.6	121
200	4.9	8.7	1.9	4.0	3.1	3.2	4.1	2.2	1.8	1.7	200
201	5.0	9.6	2.4	5.6	3.4	1.9	3.7	2.4	2.3	1.7	201
210	5.2	16.0	4.2	9.3	3.0	4.3	3.9	4.0	1.9	3.1	210
211	4.8	13.6	2.8	8.4	3.0	3.8	3.3	3.8	2.1	1.8	211
220	8.9	31.3	4.9	26.5	4.7	11.7	4.3	8.4	2.3	1.9	220
221	3.3	24.0	3.0	16.5	2.6	4.5	2.8	3.6	2.0	2.6	221

APPENDIX III. Results of the Oat Experiment (1962).

Table 36. Layout of the oat experiment (1962).

Treatment					
STNKMg	STNKMg	STNKMg	STNKMg	STNKMg	STNKMg
Block 1					
B1202	A0202	A1120	B0120	B0112	A0112
B0202	A1202	B1120	A0120	A1112	B1112
A0000	B0000	B0011	A1011	A0210	B1210
A1000	B1000	A0011	B1011	B0210	A1210
B0022	B1022	A0101	B1101	B1221	B0221
A0022	A1022	A1101	B0101	A1221	A0221
Block 2					
A1121	B1121	B1110	A0110	B1020	B0020
A0121	B0121	A1110	B0110	A0020	A1020
A1222	A0222	B0102	A1102	A0012	B0012
B1222	B0222	A0102	B1102	A1012	B1012
A1200	B1200	A1001	B0001	B1211	A0211
A0200	B0200	B1001	A0001	A1211	B0211
Block 3					
B0212	A1202	B0021	A1021	A0002	A1002
A0212	B1202	B1021	A0021	B0002	B1002
A1010	B0010	A1111	B0111	A1122	A0122
B1010	A0010	B1111	A0111	B1122	B0122
B0220	B1220	B0100	B1100	B0201	A0201
A1220	A0220	A0100	A1100	B1201	A1201

$T_0 = (NH_4)_2SO_4$ $T_1 = Ca(NO_3)_2$

Table 37. Weekly weather data for the oat experiment (1962). The observations were made at Bush House, 1½ miles west of the experimental site.

Date (1962)	Precipitation (in.)			Temperature (°F)		Sunshine (hours)
	Rainfall	Added water	Total	Max.	Min.	
26– 1 Apr.	0.45	0.67	1.12	45.0	32.6	30.7
2– 8 "	2.40	0.00	2.40	43.6	33.0	18.4
9–15 "	0.11	0.67	0.78	47.3	32.3	57.4
16–22 "	0.59	0.67	1.26	48.3	38.0	16.3
23–29 "	0.00	1.08	1.08	58.3	38.9	57.0
30– 6 May	0.37	0.54	0.91	58.1	38.0	40.7
7–13 "	1.20	0.27	1.47	56.1	42.9	19.0
14–20 "	1.02	0.00	1.02	53.9	40.6	45.7
21–27 "	0.28	0.30	0.58	51.7	40.1	32.2
28– 3 June	0.27	0.27	0.54	57.0	38.4	45.9
4–10 "	0.00	2.42	2.42	68.3	44.3	63.9
11–17 "	0.24	2.55	2.79	61.3	45.6	34.4
18–24 "	0.46	0.67	1.13	60.4	49.4	31.9
25– 1 July	0.21	2.02	2.43	60.3	45.4	29.1
2– 8 "	0.03	0.27	0.30	59.7	46.1	24.4

Table 38. Oat experiment (1962): fresh yield (g/pot).

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				after "heading"				Treatment
	$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		
NKMg	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	NKMg
000	7.2	6.3	6.7	6.7	12.2	12.5	12.5	13.6	22.4	17.4	18.7	16.5	22.5	18.0	22.5	20.0	000
001	5.6	6.7	5.8	6.3	12.9	15.1	12.1	15.3	20.0	21.8	18.4	22.8	20.5	22.0	21.5	21.5	001
002	6.3	6.7	6.4	6.9	12.6	14.6	13.5	13.7	16.7	21.5	17.4	21.0	19.0	22.5	20.5	21.0	002
010	6.4	7.1	7.5	6.8	12.3	12.9	11.7	15.2	19.1	18.3	17.0	21.0	22.0	24.0	20.0	21.0	010
011	7.1	8.5	6.0	7.5	11.6	13.1	12.6	13.5	18.0	21.7	18.7	23.7	21.0	22.0	18.5	23.0	011
012	5.9	6.7	6.2	7.7	12.9	14.5	13.7	17.4	17.6	22.2	16.1	20.2	20.0	24.0	18.0	26.0	012
020	6.4	7.3	6.1	7.8	13.5	15.7	13.0	16.3	18.3	22.0	20.9	23.8	20.0	25.0	26.0	26.0	020
021	6.5	9.1	6.0	7.8	12.6	14.5	11.9	18.5	16.4	21.6	16.5	22.7	19.0	25.0	21.0	25.0	021
022	6.9	6.7	6.5	7.0	11.8	12.7	12.2	14.0	19.4	18.4	17.0	16.7	20.5	22.0	22.5	23.0	022
100	14.5	17.1	8.1	9.0	28.9	35.4	26.6	27.5	45.0	59.1	42.2	45.3	53.0	72.5	50.0	56.5	100
101	10.3	14.5	7.1	7.9	26.2	30.4	24.6	26.0	47.7	55.6	47.7	46.6	61.0	69.5	56.5	58.0	101
102	9.9	14.1	5.7	7.2	27.9	38.1	25.5	28.3	43.0	60.2	44.0	48.1	62.0	72.0	60.5	61.0	102
110	7.7	14.8	6.2	6.4	27.1	36.5	28.3	25.7	42.3	55.1	45.2	42.0	56.0	78.0	62.0	60.0	110
111	10.4	17.8	7.5	7.0	27.1	37.9	26.8	31.1	46.7	58.9	43.9	45.7	57.0	79.0	64.0	63.0	111
112	16.1	18.4	6.7	8.1	23.3	32.7	24.0	26.5	34.9	42.7	41.0	36.4	55.0	58.0	42.5	55.0	112
120	12.7	18.3	7.8	9.0	27.8	36.2	26.0	27.3	42.1	42.3	34.7	41.4	60.0	72.0	63.5	64.0	120
121	9.6	14.1	6.7	6.7	24.1	36.8	22.6	25.9	42.8	55.8	45.5	43.1	55.0	74.5	57.0	60.0	121
122	11.2	17.1	8.0	9.5	28.1	38.2	14.5	29.7	40.9	50.4	41.4	42.5	58.0	76.0	60.5	56.0	122
200	15.0	18.8	5.7	6.9	31.4	38.5	28.5	30.1	49.7	61.2	50.7	55.2	84.0	90.0	69.5	75.0	200
201	22.9	22.3	11.9	13.4	42.2	45.1	29.8	30.1	50.7	54.9	42.0	45.7	80.0	76.0	61.0	56.5	201
202	23.5	19.8	7.1	12.6	36.2	41.4	32.6	28.1	49.9	62.5	46.4	42.5	92.5	80.0	78.0	67.5	202
210	19.7	21.1	7.5	7.5	39.7	37.6	24.9	28.0	54.9	59.6	43.9	42.3	89.0	85.0	70.0	60.0	210
211	20.1	17.3	6.0	8.5	38.8	35.3	34.9	34.7	50.0	49.7	46.9	48.6	81.5	74.0	77.0	67.5	211
212	14.5	18.1	7.4	8.8	35.1	37.0	28.0	33.4	65.0	56.0	47.7	56.1	92.5	88.0	79.5	77.0	212
220	20.5	23.0	9.5	9.1	39.8	41.3	31.3	34.5	57.1	68.7	47.0	59.6	72.5	76.5	58.0	67.5	220
221	20.9	17.2	6.9	10.1	30.9	33.3	29.9	28.1	53.1	55.0	50.9	52.5	87.0	80.0	71.0	66.0	221
222	17.5	18.9	6.1	7.9	50.0	45.1	28.7	28.0	72.4	70.4	52.3	52.8	97.0	86.5	73.0	68.5	222

Note: In tables 38 - 51, the letters A and B are used to denote the soils.

Table 39. Oat experiment (1962): yield of dry matter (g/pot).

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				after "heading"				Treatment
	$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		
NKMg	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	NKMg
000	1.18	1.15	1.10	1.22	2.51	2.91	2.60	3.14	5.0	4.0	4.1	3.8	5.7	4.6	5.5	5.1	000
001	0.92	1.28	1.00	1.12	2.79	3.50	2.65	3.61	4.6	5.2	4.2	5.6	5.1	6.2	5.2	6.2	001
002	1.11	1.22	1.09	1.28	2.80	3.46	3.00	3.29	3.7	5.1	3.9	5.0	5.1	6.1	5.3	5.7	002
010	1.10	1.30	1.10	1.25	2.60	3.02	2.50	3.67	4.4	4.3	3.8	5.1	5.5	6.4	4.9	5.6	010
011	1.12	1.52	0.98	1.41	2.40	3.00	2.60	3.08	4.1	5.1	4.1	5.6	5.3	6.1	4.6	6.2	011
012	0.99	1.24	1.00	1.47	2.83	3.40	2.94	4.08	3.9	5.5	3.4	4.8	4.9	6.3	4.5	7.0	012
020	1.04	1.26	1.02	1.38	2.90	3.80	2.81	3.82	4.0	5.3	5.0	5.7	5.0	6.7	6.9	6.9	020
021	1.07	1.70	1.02	1.46	2.62	3.40	2.56	4.27	3.6	5.2	3.7	5.3	4.7	6.7	5.5	6.7	021
022	1.10	1.31	1.10	1.30	2.50	2.98	2.58	3.23	3.7	4.5	3.7	4.2	5.2	5.7	5.8	5.9	022
100	2.48	3.18	1.34	1.65	6.20	8.49	4.63	5.20	11.0	15.2	10.2	11.0	15.0	21.2	13.7	15.8	100
101	1.71	2.50	1.11	1.42	5.50	7.55	4.39	5.08	11.5	15.0	11.3	11.3	16.9	20.0	15.3	15.9	101
102	1.68	2.48	0.91	1.39	5.95	9.11	4.38	5.60	11.3	15.2	11.1	12.1	16.7	20.6	15.6	16.7	102
110	1.31	2.48	1.00	1.19	5.92	8.35	5.23	5.12	10.4	15.0	11.3	10.1	15.7	22.1	16.4	17.2	110
111	1.83	3.08	1.29	1.20	5.48	9.10	4.93	6.62	11.9	16.8	10.9	11.0	15.7	22.1	17.3	17.5	111
112	2.31	2.94	1.09	1.47	5.10	8.00	4.17	5.32	9.5	11.9	10.5	10.1	15.4	17.5	15.0	15.8	112
120	2.03	3.00	1.17	1.59	5.51	8.29	4.61	5.39	11.1	12.6	9.3	10.5	15.9	21.0	16.9	17.9	120
121	1.60	2.39	1.29	1.23	4.89	8.34	4.45	5.01	10.8	14.5	11.4	10.8	15.4	21.2	15.7	16.8	121
122	1.87	2.90	1.38	1.73	6.17	8.87	4.40	5.85	11.3	13.9	10.7	11.0	16.4	21.4	16.2	16.6	122
200	2.34	2.88	0.90	1.22	6.79	8.99	4.94	5.78	15.6	16.6	12.3	14.2	24.0	25.8	18.0	21.0	200
201	3.68	3.86	1.93	2.37	9.16	10.53	5.20	5.30	14.2	16.4	11.1	12.7	22.0	21.8	16.3	17.5	201
202	3.38	3.48	1.18	2.10	7.80	9.62	5.54	5.39	13.0	15.9	11.0	10.3	25.8	25.0	20.2	19.2	202
210	3.00	3.48	1.19	1.38	8.10	8.69	4.61	5.35	15.8	17.5	12.2	11.1	25.0	24.3	18.3	16.9	210
211	2.85	2.73	0.95	1.57	8.67	8.66	5.88	6.30	14.0	14.4	12.0	11.3	23.0	21.8	20.8	19.0	211
212	2.25	3.24	1.27	1.63	7.34	8.73	4.52	6.21	17.1	16.5	11.5	14.1	25.7	25.6	20.6	22.1	212
220	3.40	3.72	1.54	1.72	8.34	9.87	5.09	6.10	15.7	19.7	11.7	15.0	20.6	22.9	15.3	19.1	220
221	3.13	2.68	1.11	1.69	6.89	7.90	4.79	5.19	15.1	16.5	12.9	13.0	25.0	23.4	18.8	18.6	221
222	2.88	3.23	0.90	1.47	8.19	10.71	4.62	5.02	18.3	18.8	12.4	12.7	27.3	25.7	19.0	19.6	222

Table 40. Oat experiment (1962): % dry matter in oats.

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				after "heading"				Treatment
	$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		
NKMg	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	NKMg
000	16.3	18.1	16.5	18.2	20.6	23.3	20.8	23.1	22.5	22.9	21.8	23.0	25.3	25.6	24.7	25.3	000
001	16.5	19.1	17.1	17.7	21.6	23.2	21.9	23.6	23.0	23.8	22.4	24.7	24.9	28.2	24.4	28.8	001
002	17.5	18.2	17.1	18.6	22.2	23.7	22.2	24.0	22.1	23.8	22.6	23.7	26.8	27.1	25.9	27.1	002
010	17.1	18.3	14.8	18.4	21.1	23.4	21.3	24.2	22.7	23.5	22.3	24.1	25.0	26.7	24.5	26.7	010
011	15.9	18.0	16.4	18.7	20.7	22.9	20.6	22.9	22.9	23.7	21.8	23.5	25.2	27.7	24.9	27.0	011
012	16.8	18.4	16.2	19.0	22.0	23.5	21.4	23.5	22.4	24.6	21.1	23.9	24.5	26.3	25.0	26.9	012
020	16.3	17.3	16.8	17.7	21.5	24.2	21.6	23.4	21.8	24.3	23.9	24.0	25.0	26.8	26.5	26.4	020
021	16.5	18.7	16.9	18.8	20.8	23.4	21.5	23.1	21.8	23.9	22.3	23.3	24.7	26.8	26.2	26.8	021
022	16.1	19.4	17.1	18.6	21.2	23.5	21.2	23.1	19.2	24.4	21.6	25.1	25.4	25.9	25.8	25.7	022
100	17.0	18.6	16.5	18.3	21.5	24.0	17.4	18.9	24.3	25.7	24.2	24.4	28.3	29.2	27.4	28.0	100
101	16.6	17.3	15.7	18.0	21.0	24.8	17.9	19.5	24.1	27.0	23.6	24.2	27.7	28.8	27.1	27.4	101
102	16.9	17.7	15.8	19.4	21.3	23.9	17.2	19.8	26.2	25.2	25.1	25.2	26.9	28.6	25.8	27.4	102
110	17.1	16.8	16.1	18.7	21.8	22.9	18.5	19.9	24.5	27.2	25.0	24.0	28.0	28.3	26.5	28.7	110
111	17.6	17.3	17.2	17.1	20.2	24.0	18.4	21.3	25.4	28.6	24.8	24.0	27.5	28.0	27.0	27.7	111
112	14.4	16.0	16.4	18.3	21.9	24.5	17.4	20.1	27.2	27.9	25.6	27.7	28.0	30.2	26.4	28.7	112
120	15.9	16.4	15.0	17.7	19.8	22.9	17.7	19.8	26.4	29.8	26.7	25.3	26.6	29.2	26.6	28.0	120
121	16.7	16.9	19.1	18.5	20.3	22.7	19.7	19.4	25.2	26.0	25.1	25.0	28.0	28.5	27.5	28.0	121
122	16.7	16.9	17.3	18.3	22.0	23.2	18.9	19.7	27.6	27.5	25.9	25.9	28.3	28.2	26.8	29.6	122
200	15.6	15.3	15.9	17.7	21.6	23.3	17.4	19.2	31.4	26.9	24.3	25.7	28.6	28.7	25.9	28.0	200
201	16.1	17.3	16.3	17.7	21.7	23.3	17.4	17.6	27.9	29.8	26.4	27.7	27.5	28.7	26.7	31.0	201
202	14.4	17.6	16.7	16.7	21.5	23.2	17.0	19.2	26.0	25.5	23.7	24.3	27.9	31.3	25.9	28.4	202
210	15.2	16.5	16.0	18.4	20.4	23.1	18.5	19.1	28.7	29.3	27.7	26.3	28.1	28.6	26.1	28.2	210
211	14.2	15.7	15.8	18.4	22.4	24.5	16.8	18.1	28.1	29.0	25.6	23.2	28.2	29.5	27.0	28.2	211
212	15.6	17.9	17.3	18.5	20.9	23.6	16.1	18.6	26.3	29.4	24.1	25.1	27.8	29.1	25.9	28.7	212
220	16.6	16.2	16.1	18.9	21.0	23.9	16.3	17.7	27.5	28.7	24.9	25.2	28.4	29.9	26.4	28.3	220
221	14.9	15.6	16.2	16.7	22.3	23.7	16.0	18.5	28.5	30.0	25.3	24.8	28.7	29.3	26.5	28.2	221
222	16.4	17.1	14.9	18.7	19.5	23.8	16.1	18.0	25.2	26.7	23.7	24.0	28.1	29.7	26.0	28.6	222

Table 41. Oat experiment (1962): % Mg content of oats.

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				after "heading"				Treatment
	$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		
NKMg	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	NKMg
000	.175	.167	.154	.145	.165	.159	.165	.140	.123	.120	.133	.130	.119	.107	.121	.119	000
001	.211	.210	.211	.179	.193	.148	.176	.149	.134	.133	.138	.101	.133	.113	.135	.094	001
002	.215	.207	.221	.208	.198	.156	.139	.158	.149	.136	.149	.152	.129	.135	.153	.120	002
010	.189	.133	.138	.201	.167	.134	.169	.130	.130	.115	.143	.115	.123	.099	.126	.107	010
011	.186	.155	.185	.153	.180	.135	.171	.138	.094	.123	.136	.121	.118	.111	.113	.096	011
012	.192	.178	.209	.181	.177	.167	.172	.142	.150	.135	.163	.137	.139	.113	.131	.122	012
020	.146	.136	.146	.139	.140	.120	.148	.113	.131	.114	.121	.116	.116	.103	.110	.110	020
021	.183	.167	.171	.167	.163	.130	.170	.126	.136	.121	.134	.121	.124	.110	.121	.102	021
022	.137	.158	.165	.174	.187	.159	.196	.164	.153	.138	.150	.137	.134	.133	.148	.123	022
100	.153	.157	.166	.152	.167	.141	.206	.198	.122	.109	.129	.118	.123	.106	.131	.109	100
101	.183	.192	.202	.172	.181	.155	.249	.210	.118	.131	.120	.120	.094	.115	.130	.098	101
102	.228	.199	.240	.164	.171	.167	.252	.211	.136	.128	.137	.130	.120	.118	.101	.113	102
110	.146	.155	.156	.151	.158	.141	.194	.186	.117	.111	.132	.110	.097	.094	.090	.093	110
111	.173	.163	.178	.204	.158	.147	.204	.179	.119	.120	.114	.115	.111	.106	.109	.116	111
112	.201	.201	.205	.173	.171	.166	.244	.199	.147	.126	.149	.148	.120	.122	.102	.123	112
120	.133	.148	.129	.133	.135	.122	.191	.175	.110	.094	.134	.117	.098	.107	.104	.105	120
121	.163	.159	.151	.189	.161	.147	.202	.203	.114	.118	.095	.127	.105	.102	.117	.113	121
122	.174	.193	.181	.176	.157	.143	.192	.196	.139	.129	.133	.144	.114	.112	.115	.119	122
200	.189	.196	.198	.149	.190	.142	.273	.243	.146	.129	.178	.157	.129	.120	.160	.140	200
201	.211	.199	.193	.181	.180	.171	.286	.280	.162	.155	.204	.165	.132	.117	.159	.132	201
202	.197	.205	.210	.188	.186	.194	.324	.280	.189	.145	.206	.181	.142	.142	.146	.155	202
210	.176	.163	.166	.133	.184	.146	.265	.214	.136	.112	.168	.146	.129	.115	.149	.102	210
211	.187	.201	.180	.153	.155	.159	.264	.249	.152	.135	.175	.126	.137	.111	.135	.121	211
212	.152	.135	.156	.123	.195	.176	.311	.254	.142	.141	.171	.160	.125	.107	.123	.141	212
220	.149	.202	.157	.176	.156	.122	.251	.204	.129	.111	.158	.120	.122	.108	.151	.125	220
221	.177	.185	.172	.178	.165	.146	.266	.250	.134	.124	.164	.146	.110	.118	.145	.134	221
222	.163	.173	.213	.175	.170	.172	.294	.250	.136	.132	.174	.156	.118	.124	.138	.132	222

Table 42. Oat experiment (1962): Mg uptake by oats (mg/pot).

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				after "heading"				Treatment
	$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		
NKMg	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	NKMg
000	2.07	1.92	1.69	1.77	4.1	4.6	4.3	4.4	6.2	4.8	5.4	4.9	6.8	4.9	6.7	6.1	000
001	1.94	2.69	2.11	2.01	5.4	5.2	4.7	5.4	6.2	6.9	5.8	5.7	6.8	7.0	7.0	5.8	001
002	2.39	2.53	2.41	2.66	5.5	5.4	4.2	5.2	5.5	7.0	5.8	7.6	6.6	8.2	8.1	6.8	002
010	2.08	1.73	1.52	2.51	4.3	4.0	4.2	4.8	5.7	4.9	5.4	5.8	6.8	6.3	6.2	6.0	010
011	2.08	2.36	1.81	2.18	4.3	4.0	4.4	4.3	3.9	6.3	5.5	6.8	6.3	6.8	5.2	6.0	011
012	1.90	2.21	2.09	2.66	5.0	5.7	5.1	5.8	5.9	7.4	5.5	6.6	6.8	7.1	5.9	8.5	012
020	1.52	1.71	1.49	1.92	4.1	4.6	4.2	4.3	5.2	6.1	6.0	6.6	5.8	6.9	7.6	7.6	020
021	1.96	2.84	1.74	2.44	4.3	4.4	4.4	5.4	4.9	6.2	4.9	6.4	5.8	7.4	6.7	6.8	021
022	1.51	2.07	1.82	2.26	4.7	4.7	5.1	5.3	5.7	6.2	5.5	5.8	7.0	7.6	8.6	7.3	022
100	3.79	4.99	2.22	2.51	10.4	12.0	9.5	10.3	13.4	16.5	13.2	13.0	18.5	22.5	17.9	17.2	100
101	3.13	4.80	2.24	2.44	10.0	11.7	10.9	10.7	13.6	19.6	13.5	13.5	15.9	23.0	19.9	15.6	101
102	2.83	4.94	2.18	2.28	10.2	15.2	11.0	11.8	15.3	19.4	15.1	15.7	20.0	24.3	15.8	18.9	102
110	1.91	3.84	1.56	1.80	9.4	11.8	10.1	9.5	12.1	16.6	14.9	11.1	15.2	20.8	14.8	16.0	110
111	3.17	5.02	2.30	2.45	8.7	13.4	10.1	11.9	14.1	20.2	12.4	12.6	17.4	23.4	18.9	20.3	111
112	4.64	5.91	2.24	2.54	8.7	13.3	10.2	10.6	14.0	15.0	15.6	14.9	18.5	21.4	15.3	19.4	112
120	2.70	4.44	1.51	2.12	7.4	10.1	8.8	9.4	12.2	11.9	12.4	12.3	15.6	22.5	17.6	18.8	120
121	2.61	3.80	1.95	2.33	7.9	12.3	9.0	10.2	12.3	17.1	10.8	13.7	16.2	21.6	18.4	19.0	121
122	3.25	5.60	2.50	3.05	9.7	12.7	8.4	11.5	15.7	17.9	14.2	15.8	18.7	24.0	18.6	19.8	122
200	4.42	5.65	1.78	1.82	12.9	12.8	13.5	14.0	22.8	21.2	21.9	22.3	31.0	31.0	28.8	29.4	200
201	7.77	7.68	3.73	4.29	16.5	18.0	14.9	14.8	22.9	25.4	22.6	20.9	29.0	25.5	25.9	23.1	201
202	6.66	7.13	2.48	3.95	14.5	18.7	18.0	15.1	24.5	23.1	22.6	18.7	36.6	35.5	29.5	29.8	202
210	5.28	5.67	1.98	1.84	14.9	12.7	12.2	11.4	21.5	19.6	20.4	16.3	32.3	27.9	27.3	17.2	210
211	5.33	5.49	1.71	2.40	13.4	13.8	15.5	15.7	21.3	19.5	21.1	14.2	31.6	24.2	28.1	23.0	211
212	3.42	4.37	1.98	2.01	14.3	15.4	14.1	15.8	24.3	23.2	19.6	22.5	32.1	27.4	25.3	31.2	212
220	5.07	7.51	2.42	3.03	13.0	12.0	13.0	12.4	20.3	21.9	18.5	18.0	25.1	24.7	23.1	23.9	220
221	5.54	4.96	1.91	3.01	11.4	11.5	12.7	13.0	20.2	20.5	21.1	19.0	27.5	27.6	27.3	24.9	221
222	4.69	5.59	1.92	2.57	13.9	18.4	13.6	12.6	24.8	24.8	21.6	19.8	32.2	31.9	26.2	25.9	222

Table 43. Oat experiment (1962): % Ca content of oats.

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				after "heading"				Treatment
	$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		
NKMg	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	NKMg
000	.79	.47	.78	.46	.57	.29	.55	.30	.33	.21	.33	.24	.19	.15	.21	.15	000
001	.85	.42	.84	.49	.52	.26	.54	.26	.26	.18	.32	.15	.25	.13	.21	.12	001
002	.78	.37	.77	.41	.47	.21	.38	.20	.30	.18	.31	.15	.22	.15	.29	.12	002
010	.77	.60	.72	.36	.56	.31	.57	.27	.27	.18	.34	.18	.22	.12	.20	.13	010
011	.79	.31	.79	.36	.54	.27	.58	.27	.30	.15	.33	.18	.20	.13	.19	.15	011
012	.81	.40	.81	.37	.46	.25	.45	.23	.32	.18	.33	.20	.24	.12	.22	.15	012
020	.89	.45	.81	.40	.46	.28	.53	.25	.29	.16	.28	.16	.22	.13	.21	.14	020
021	.86	.40	.86	.42	.45	.20	.43	.20	.31	.16	.31	.17	.22	.16	.26	.16	021
022	.71	.35	.72	.34	.52	.25	.55	.27	.32	.18	.31	.18	.18	.14	.22	.15	022
100	.68	.39	.74	.45	.47	.20	.56	.31	.28	.20	.29	.18	.26	.19	.28	.19	100
101	.68	.39	.93	.40	.52	.28	.65	.37	.29	.17	.24	.17	.20	.17	.27	.15	101
102	.74	.35	.84	.37	.49	.25	.54	.32	.28	.16	.24	.17	.20	.15	.18	.14	102
110	.83	.39	.89	.50	.45	.24	.53	.30	.28	.20	.32	.20	.19	.15	.17	.13	110
111	.70	.38	.80	.48	.40	.18	.43	.23	.27	.15	.23	.17	.23	.14	.21	.17	111
112	.63	.36	.78	.38	.48	.24	.54	.33	.36	.21	.32	.27	.20	.15	.22	.15	112
120	.59	.35	.72	.36	.48	.27	.51	.30	.29	.20	.34	.21	.18	.13	.18	.15	120
121	.68	.38	.47	.64	.44	.22	.56	.29	.28	.18	.27	.20	.20	.13	.21	.15	121
122	.58	.36	.74	.33	.38	.19	.55	.29	.27	.17	.26	.16	.19	.15	.22	.13	122
200	.72	.43	.88	.51	.56	.31	.68	.41	.37	.26	.42	.25	.32	.23	.36	.21	200
201	.64	.36	.74	.41	.48	.29	.71	.40	.37	.22	.43	.27	.34	.22	.35	.22	201
202	.54	.39	.72	.32	.46	.30	.63	.40	.40	.22	.38	.27	.29	.20	.23	.20	202
210	.59	.38	.79	.42	.55	.35	.73	.44	.41	.23	.46	.29	.25	.18	.27	.20	210
211	.58	.32	.81	.40	.47	.28	.59	.36	.40	.23	.40	.25	.33	.19	.24	.17	211
212	.40	.42	.88	.45	.46	.23	.64	.37	.30	.20	.36	.23	.23	.15	.23	.16	212
220	.45	.64	.88	.41	.47	.29	.64	.35	.30	.22	.36	.20	.32	.18	.38	.19	220
221	.49	.33	.70	.41	.54	.31	.67	.38	.36	.21	.35	.20	.25	.16	.24	.17	221
222	.52	.30	.83	.40	.40	.25	.60	.36	.29	.20	.37	.23	.21	.15	.26	.15	222

Table 44. Oat experiment (1962): Ca uptake by oats (mg/pot).

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				after "heading"				Treatment
	$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		
NKMg	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	NKMg
000	9.3	5.4	8.6	5.6	14.3	8.4	14.3	9.4	16.6	8.4	13.5	9.1	10.8	6.9	11.6	7.7	000
001	7.8	5.4	8.4	5.5	14.5	9.1	14.3	9.4	12.0	9.4	13.5	8.4	12.8	8.1	10.9	7.4	001
002	8.7	4.5	8.4	5.2	13.2	7.3	11.4	6.6	11.1	9.2	12.2	7.5	11.2	9.2	15.4	6.8	002
010	8.5	7.8	7.9	4.5	14.6	9.4	14.3	9.9	11.7	7.7	12.9	9.1	12.1	7.7	9.8	7.3	010
011	8.8	4.7	7.7	5.1	13.0	8.1	15.1	8.3	12.4	7.7	13.5	10.0	10.6	7.9	8.7	9.3	011
012	8.0	5.0	8.1	5.4	13.0	8.5	13.2	9.4	12.6	9.8	11.2	9.7	11.8	7.6	9.9	10.5	012
020	9.3	5.7	8.3	5.5	13.3	10.6	14.9	9.6	11.5	8.5	13.9	9.1	11.0	8.7	14.5	9.7	020
021	9.2	6.8	8.8	6.1	11.8	6.8	11.0	8.5	11.1	8.3	11.4	9.0	10.3	10.7	14.3	10.7	021
022	7.8	4.6	7.9	4.4	13.0	7.5	14.2	8.7	11.9	8.1	11.4	7.6	9.4	8.0	12.8	8.9	022
100	16.9	12.4	9.9	7.4	29.1	17.0	25.9	16.1	30.7	30.3	29.6	19.8	39.0	40.3	38.4	30.0	100
101	11.6	9.8	10.3	5.7	28.6	21.1	28.5	18.8	33.3	25.4	27.0	19.2	33.8	34.0	41.3	23.9	101
102	12.4	8.7	7.6	5.1	29.2	22.8	23.7	17.9	31.6	24.3	26.5	20.6	33.4	30.9	28.1	23.4	102
110	10.9	9.7	8.9	6.0	26.6	20.0	27.7	15.4	29.0	29.9	36.1	20.2	29.8	33.2	27.9	22.4	110
111	12.8	11.7	10.3	5.8	21.9	16.4	21.2	15.2	32.0	25.2	25.0	18.7	36.1	30.9	36.3	29.8	111
112	14.6	10.6	8.5	5.6	24.5	19.2	22.5	17.6	34.2	25.0	33.5	27.2	30.8	26.3	33.0	23.7	112
120	12.0	10.5	8.4	5.7	26.4	22.4	23.5	16.2	32.2	25.2	31.5	22.0	28.6	27.3	30.4	26.9	120
121	10.9	9.1	6.1	7.9	21.5	18.3	24.9	14.5	30.2	26.1	30.8	21.6	30.8	27.6	33.0	25.2	121
122	10.8	10.4	10.2	5.7	23.4	16.9	24.2	17.0	30.4	23.6	27.8	17.6	31.2	32.1	35.6	21.6	122
200	16.8	12.4	7.9	6.2	38.0	27.9	33.6	23.7	57.7	42.8	51.7	35.5	76.8	59.3	64.8	44.1	200
201	23.6	13.9	14.3	9.7	44.0	30.5	36.9	21.2	52.4	36.0	47.6	34.2	74.8	48.0	57.1	38.5	201
202	18.3	13.6	8.5	6.7	35.9	28.9	34.9	21.6	51.8	35.0	41.7	27.9	74.8	50.0	46.5	38.4	202
210	17.7	13.2	9.4	5.8	44.6	30.4	33.7	23.5	64.7	40.2	56.0	32.3	62.5	43.7	49.4	33.8	210
211	16.5	8.7	7.7	6.3	40.7	24.2	34.7	22.7	56.1	33.2	48.2	28.2	75.9	41.4	49.9	32.3	211
212	9.0	13.6	11.2	7.3	33.8	20.1	28.9	23.0	51.3	32.9	41.3	32.4	59.1	38.4	47.4	35.4	212
220	15.3	23.8	13.6	7.1	39.2	28.6	33.2	21.4	47.1	43.4	42.2	30.0	65.9	41.2	58.1	36.3	220
221	15.3	8.8	7.8	6.9	37.2	24.5	32.1	19.7	54.3	34.7	45.1	26.1	62.5	37.4	45.1	31.6	221
222	15.0	9.7	7.5	5.9	32.8	26.8	27.7	18.1	53.0	37.6	45.9	29.2	57.3	38.6	49.4	29.4	222

Table 45. Oat experiment (1962): % K content of oats.

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				after "heading"				Treatment
	$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		
NKMg	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	NKMg
000	2.82	2.21	3.84	3.61	2.89	2.55	2.89	2.56	2.35	2.34	2.39	2.31	2.16	2.09	2.16	2.08	000
001	3.50	3.27	3.50	3.25	2.94	2.65	2.97	2.65	2.32	2.20	2.40	1.91	2.13	2.00	2.08	1.44	001
002	3.43	3.41	3.57	3.57	2.80	2.43	2.28	2.52	2.35	2.10	2.29	2.34	2.09	2.05	2.05	2.03	002
010	3.47	3.42	3.82	3.14	3.11	2.74	3.10	2.53	2.44	2.28	2.56	2.23	2.08	1.94	2.13	2.02	010
011	3.84	3.49	3.99	3.47	3.08	2.52	2.89	2.74	1.79	2.29	2.42	2.20	2.18	2.06	2.20	2.02	011
012	3.61	3.32	3.56	3.24	3.14	2.73	2.91	2.64	2.46	2.18	2.71	2.23	2.27	1.98	2.26	1.94	012
020	3.74	3.63	3.74	3.46	3.16	2.65	3.16	2.56	2.53	2.39	2.43	2.28	2.20	2.00	2.03	2.11	020
021	3.75	3.29	3.58	3.21	3.26	2.70	3.11	2.65	2.56	2.27	2.58	2.27	2.38	2.13	2.29	2.08	021
022	3.84	3.49	3.57	3.57	2.98	2.53	3.05	2.58	2.50	2.32	2.52	2.36	2.21	2.08	2.18	2.09	022
100	2.74	3.14	3.77	3.50	2.34	2.06	2.80	2.89	1.50	1.31	1.50	1.68	1.15	1.02	1.21	1.22	100
101	3.20	3.14	3.42	3.46	2.52	1.85	2.85	2.88	1.43	1.33	1.36	1.60	1.12	1.05	1.05	1.19	101
102	2.82	3.14	3.35	3.10	2.41	1.83	3.04	2.96	1.52	1.22	1.48	1.56	1.09	0.99	1.13	1.23	102
110	3.44	3.54	3.64	3.29	2.94	2.22	3.22	3.11	1.96	1.61	1.84	1.91	1.44	1.21	1.43	1.35	110
111	3.59	3.61	3.61	4.05	2.89	2.35	3.46	2.85	1.84	1.67	1.78	1.87	1.52	1.26	1.43	1.48	111
112	3.89	3.47	3.96	3.36	2.99	2.15	3.42	2.97	2.06	1.81	1.89	2.00	1.32	1.27	1.06	1.37	112
120	3.92	3.72	4.17	3.88	3.08	2.43	3.32	3.01	2.11	1.91	2.44	2.04	1.63	1.38	1.68	1.60	120
121	3.69	3.76	3.57	3.42	3.21	2.52	3.54	3.27	2.02	1.67	1.75	1.93	1.51	1.34	1.67	1.54	121
122	3.90	3.81	3.79	3.54	3.04	2.43	2.94	3.17	2.12	1.80	2.03	2.01	1.56	1.47	1.54	1.54	122
200	2.55	3.49	3.39	3.30	2.12	1.90	3.42	2.73	1.11	1.26	1.47	1.44	0.76	0.85	1.02	0.92	200
201	2.43	3.02	3.24	3.13	1.74	1.67	2.71	2.91	1.21	1.22	1.46	1.50	0.92	1.01	1.12	1.09	201
202	3.17	3.04	3.84	3.46	2.29	1.70	2.74	2.85	1.54	1.24	1.69	1.79	0.96	0.89	1.07	1.10	202
210	3.32	3.69	4.04	3.69	2.20	2.29	3.44	3.50	1.23	1.45	1.79	1.93	0.87	1.16	1.22	1.30	210
211	3.30	3.85	3.81	3.49	2.24	2.11	3.13	3.22	1.48	1.64	1.84	1.79	1.03	1.15	1.21	1.22	211
212	3.69	3.44	3.68	3.36	2.46	2.01	3.16	3.19	1.31	1.37	1.63	1.68	0.92	0.97	1.11	1.08	212
220	3.42	3.72	3.67	3.30	2.64	2.17	3.39	3.59	1.62	1.60	2.07	1.87	1.30	1.21	1.54	1.40	220
221	3.74	4.36	3.98	3.81	2.73	2.47	3.69	3.61	1.70	1.83	2.11	1.94	1.21	1.33	1.65	1.42	221
222	3.61	3.51	4.18	3.44	3.01	2.29	3.54	3.42	1.75	1.52	2.16	1.85	1.19	1.14	1.50	1.38	222

Table 46. Oat experiment (1962): K uptake by oats (mg/pot)

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				after "heading"				Treatment
	$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		
NKMg	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	NKMg
000	33	25	42	44	73	74	75	80	118	93	98	88	123	96	119	106	000
001	32	42	35	36	82	93	79	96	107	114	101	107	109	124	108	89	001
002	38	42	39	46	78	84	68	83	87	108	90	117	107	125	109	116	002
010	38	44	42	39	81	83	78	93	106	98	97	113	114	124	104	113	010
011	43	53	39	49	74	76	75	84	94	117	99	123	116	126	101	125	011
012	36	41	36	48	89	93	86	108	97	119	92	108	111	125	102	136	012
020	39	46	38	48	92	101	89	98	101	128	121	130	110	134	140	146	020
021	40	56	37	47	85	92	80	113	92	117	95	120	112	143	126	139	021
022	42	46	39	46	75	75	79	83	93	104	92	99	115	119	126	123	022
100	68	100	51	58	145	175	130	150	164	199	153	185	173	216	166	193	100
101	55	79	38	49	139	140	125	146	164	199	153	180	189	210	161	189	101
102	47	78	30	43	143	167	133	166	171	185	164	189	182	204	176	205	102
110	45	88	36	39	174	185	168	159	203	241	208	193	226	267	235	232	110
111	66	111	47	49	158	214	171	189	218	281	194	205	239	278	247	259	111
112	90	102	43	49	152	172	143	158	196	215	198	201	203	222	159	216	112
120	80	112	49	62	170	201	153	162	235	241	226	214	259	290	284	286	120
121	59	90	46	42	157	210	158	164	218	242	200	208	233	284	262	259	121
122	73	110	52	61	187	216	129	185	239	250	217	221	256	315	249	256	122
200	60	101	31	40	144	171	169	158	173	208	181	204	182	219	184	193	200
201	89	117	63	74	159	176	141	154	171	200	162	190	202	220	183	191	201
202	107	106	45	73	179	164	152	154	200	197	185	185	248	223	216	211	202
210	100	128	48	51	178	199	159	187	194	253	218	215	218	282	223	220	210
211	94	105	36	55	194	183	184	203	208	237	222	202	237	251	252	232	211
212	83	111	48	55	181	175	143	198	224	226	187	236	236	248	229	239	212
220	116	138	57	57	220	214	176	219	254	316	243	281	268	277	236	267	220
221	117	117	44	64	188	195	177	187	257	302	272	253	303	311	310	264	221
222	104	113	38	51	247	245	164	172	320	286	268	235	325	293	285	270	222

Table 47. Oat experiment (1962): % Na content of oats.

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				after "heading"				Treatment
	$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		
NKMg	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	NKMg
000	.058	.040	.080	.061	.037	.038	.041	.044	.032	.029	.029	.022	.034	.025	.028	.031	000
001	.159	.065	.130	.087	.037	.027	.036	.027	.028	.024	.026	.038	.024	.031	.024	.082	001
002	.122	.044	.132	.049	.042	.029	.054	.024	.025	.024	.027	.024	.031	.036	.032	.027	002
010	.057	.060	.035	.094	.031	.025	.032	.029	.022	.024	.024	.023	.031	.029	.026	.027	010
011	.064	.055	.059	.066	.029	.034	.036	.030	.102	.021	.018	.024	.030	.028	.027	.032	011
012	.069	.044	.086	.049	.030	.030	.033	.040	.023	.023	.027	.026	.024	.020	.021	.031	012
020	.060	.056	.056	.045	.040	.043	.042	.039	.020	.030	.027	.027	.025	.036	.034	.042	020
021	.051	.044	.055	.042	.029	.030	.030	.030	.025	.027	.025	.025	.031	.038	.031	.030	021
022	.063	.056	.075	.060	.039	.035	.041	.038	.025	.022	.021	.022	.025	.025	.026	.030	022
100	.301	.059	.139	.036	.176	.075	.216	.068	.232	.168	.274	.088	.218	.183	.258	.122	100
101	.271	.103	.203	.064	.179	.123	.294	.073	.207	.157	.242	.105	.194	.154	.258	.106	101
102	.296	.106	.185	.057	.214	.116	.272	.067	.186	.186	.256	.111	.200	.145	.226	.106	102
110	.083	.071	.075	.059	.065	.059	.120	.040	.088	.115	.205	.043	.073	.101	.115	.067	110
111	.056	.056	.063	.054	.039	.049	.075	.037	.087	.075	.137	.060	.115	.111	.136	.064	111
112	.111	.070	.043	.049	.048	.097	.115	.048	.124	.096	.208	.081	.109	.082	.286	.060	112
120	.060	.055	.039	.054	.032	.048	.053	.039	.047	.062	.071	.064	.037	.068	.045	.040	120
121	.058	.066	.054	.053	.043	.040	.083	.044	.030	.068	.092	.045	.070	.062	.073	.050	121
122	.055	.050	.046	.046	.031	.032	.266	.029	.053	.051	.085	.040	.052	.053	.086	.045	122
200	.458	.293	.156	.067	.273	.123	.372	.168	.350	.202	.349	.182	.253	.203	.269	.164	200
201	.479	.148	.228	.058	.340	.184	.382	.189	.312	.176	.402	.238	.253	.155	.287	.163	201
202	.250	.187	.061	.059	.178	.183	.376	.154	.293	.151	.351	.251	.232	.183	.243	.163	202
210	.266	.078	.073	.053	.281	.114	.218	.059	.283	.162	.305	.139	.207	.149	.233	.171	210
211	.237	.168	.074	.063	.228	.092	.211	.115	.252	.123	.243	.253	.218	.141	.183	.096	211
212	.050	.038	.050	.030	.176	.110	.278	.153	.195	.115	.270	.126	.157	.124	.213	.104	212
220	.039	.120	.052	.042	.115	.078	.193	.058	.193	.116	.227	.079	.203	.073	.181	.071	220
221	.110	.071	.066	.065	.081	.043	.115	.059	.136	.083	.203	.080	.162	.083	.131	.070	221
222	.077	.080	.064	.062	.073	.058	.166	.066	.121	.096	.167	.088	.108	.080	.133	.064	222

Table 48. Oat experiment (1962): Na uptake by oats (mg/pot).

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				after "heading"				Treatment
	$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		
NKMg	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	NKMg
000	0.68	0.46	0.88	0.74	0.9	1.1	1.1	1.4	1.6	1.2	1.2	0.8	1.9	1.2	1.5	1.6	000
001	1.46	0.83	1.30	0.97	1.0	0.9	1.0	1.0	1.3	1.2	1.1	2.1	1.2	1.9	1.2	5.1	001
002	1.35	0.54	1.44	0.63	1.2	1.0	1.6	0.8	0.9	1.2	1.1	1.2	1.6	2.2	1.7	1.5	002
010	0.63	0.78	0.39	1.18	0.8	0.8	0.8	1.1	1.0	1.0	0.9	1.2	1.7	1.9	1.3	1.5	010
011	0.72	0.84	0.58	0.93	0.7	1.0	0.9	0.9	4.2	1.1	0.7	1.3	1.6	1.7	1.2	2.0	011
012	0.68	0.55	0.86	0.72	0.8	1.0	1.0	1.6	0.9	1.3	0.9	1.3	1.2	1.3	0.9	2.2	012
020	0.62	0.71	0.57	0.62	1.2	1.6	1.2	1.5	0.8	1.6	1.3	1.5	1.3	2.4	2.3	2.9	020
021	0.55	0.75	0.56	0.61	0.8	1.0	0.8	1.3	0.9	1.4	0.9	1.3	1.5	2.5	1.7	2.0	021
022	0.69	0.73	0.83	0.78	1.0	1.0	1.1	1.2	0.9	1.0	0.8	0.9	1.3	1.4	1.5	1.8	022
100	7.47	1.88	1.86	0.59	10.9	6.4	10.0	3.5	25.4	25.5	27.9	9.7	32.7	38.8	35.3	19.3	100
101	4.63	2.58	2.25	0.91	9.8	9.3	12.9	3.7	23.8	23.5	27.2	11.8	32.8	30.8	39.5	16.9	101
102	4.97	2.63	1.68	0.79	12.7	10.6	11.9	3.8	21.0	28.2	28.3	13.4	33.4	29.9	35.3	17.7	102
110	1.09	1.76	0.75	0.70	3.8	4.9	6.3	2.0	9.1	17.2	23.1	4.3	11.5	22.3	18.9	11.5	110
111	1.03	1.73	0.81	0.65	2.1	4.5	3.7	2.4	10.3	12.6	14.9	6.6	18.1	24.5	23.5	11.2	111
112	2.56	2.06	0.47	0.72	2.4	7.8	4.8	2.6	11.8	11.4	21.8	8.2	16.8	14.4	42.9	9.5	112
120	1.22	1.65	0.46	0.86	1.8	4.0	2.4	2.1	5.2	7.8	6.6	6.7	5.9	14.3	7.6	7.2	120
121	0.93	1.58	0.70	0.65	2.1	3.3	3.7	2.2	3.2	9.9	10.5	4.9	10.8	13.1	11.5	8.4	121
122	1.03	1.45	0.63	0.80	1.9	2.8	11.7	1.7	6.0	7.1	9.1	4.4	8.5	11.3	13.9	7.5	122
200	10.72	0.84	1.40	0.82	18.5	11.1	18.4	9.7	54.6	33.3	42.9	25.8	60.7	52.4	48.4	34.4	200
201	17.63	5.71	4.40	1.38	31.1	19.4	19.9	10.0	44.1	28.8	44.5	30.2	55.7	33.8	46.8	28.5	201
202	8.45	6.51	0.72	1.24	13.8	17.6	20.8	8.3	38.0	24.0	38.5	26.0	59.9	45.8	49.1	31.3	202
210	7.98	2.71	0.87	0.73	22.8	9.9	10.1	3.2	44.7	28.3	37.1	15.5	51.8	36.2	42.6	28.9	210
211	6.76	4.59	0.70	0.99	19.8	8.0	12.4	7.2	25.4	17.7	29.3	28.5	50.1	30.7	38.1	18.2	211
212	1.13	1.23	0.64	0.49	12.9	9.6	12.6	9.5	33.3	18.9	31.0	17.7	40.3	31.7	43.9	23.0	212
220	1.33	4.46	0.80	0.72	9.6	7.7	10.0	3.5	30.3	22.9	26.6	11.9	41.8	16.7	27.7	13.6	220
221	3.44	1.90	0.73	1.10	5.6	3.4	5.5	3.1	20.5	13.7	26.1	10.4	40.5	19.4	24.6	13.0	221
222	2.22	2.58	0.58	0.91	6.0	6.2	7.7	3.3	22.1	18.1	20.7	11.2	29.5	20.6	25.3	12.5	222

Table 49. Oat experiment (1962): % P content of oats.

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				after "heading"				Treatment
	$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		
NKMg	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	NKMg
000	.964	.680	.999	.652	.813	.458	.777	.472	.507	.397	.554	.369	.459	.328	.471	.348	000
001	.953	.528	.925	.609	.759	.365	.721	.400	.442	.302	.515	.237	.518	.284	.463	.193	001
002	.960	.551	.929	.579	.732	.400	.475	.370	.540	.274	.514	.334	.430	.284	.464	.288	002
010	.884	.456	.844	.263	.785	.472	.790	.379	.536	.374	.611	.314	.492	.290	.461	.281	010
011	1.062	.446	1.070	.468	.816	.389	.797	.446	.317	.327	.553	.302	.528	.313	.528	.273	011
012	1.009	.598	.965	.434	.739	.371	.675	.389	.515	.275	.602	.311	.511	.242	.507	.240	012
020	.988	.468	1.009	.508	.670	.315	.654	.284	.486	.289	.431	.276	.500	.250	.370	.279	020
021	.988	.534	.993	.523	.766	.390	.782	.369	.631	.307	.585	.315	.567	.306	.474	.273	021
022	.902	.462	.933	.400	.390	.421	.770	.406	.602	.362	.587	.355	.468	.286	.448	.300	022
100	.589	.331	1.023	.623	.429	.204	.591	.304	.283	.151	.283	.184	.210	.117	.236	.134	100
101	.864	.340	.889	.599	.486	.162	.556	.318	.297	.154	.282	.180	.218	.119	.234	.149	101
102	.698	.371	1.089	.480	.422	.164	.501	.340	.172	.146	.254	.180	.222	.137	.203	.159	102
110	.812	.387	.899	.590	.430	.206	.455	.314	.283	.145	.255	.176	.211	.126	.205	.146	110
111	.825	.352	.944	.649	.508	.209	.541	.294	.298	.141	.275	.189	.238	.124	.219	.141	111
112	.665	.317	.984	.470	.467	.157	.516	.245	.292	.125	.257	.180	.204	.133	.166	.148	112
120	.719	.265	.941	.600	.487	.182	.304	.278	.281	.136	.285	.167	.227	.133	.211	.147	120
121	.799	.395	.642	.710	.456	.201	.443	.322	.257	.143	.204	.182	.192	.120	.210	.145	121
122	.726	.300	.832	.494	.414	.168	.356	.267	.260	.132	.255	.191	.209	.130	.193	.144	122
200	.538	.332	.995	.641	.301	.162	.419	.261	.193	.138	.214	.159	.160	.111	.184	.123	200
201	.486	.258	.796	.386	.286	.150	.465	.294	.209	.124	.253	.159	.164	.109	.204	.113	201
202	.453	.242	1.024	.437	.307	.175	.399	.288	.209	.124	.245	.157	.150	.103	.177	.122	202
210	.516	.314	.992	.553	.329	.189	.470	.284	.192	.126	.236	.153	.164	.104	.193	.118	210
211	.535	.291	1.136	.444	.287	.171	.472	.270	.209	.126	.230	.143	.151	.100	.180	.126	211
212	.245	.594	1.040	.506	.316	.191	.448	.268	.198	.121	.235	.165	.158	.095	.178	.123	212
220	.647	.761	1.110	.524	.296	.132	.434	.263	.206	.125	.253	.145	.157	.103	.180	.128	220
221	.531	.288	1.004	.579	.310	.166	.447	.292	.178	.135	.242	.155	.160	.099	.194	.130	221
222	.570	.272	1.159	.643	.325	.167	.409	.261	.203	.128	.223	.161	.160	.102	.169	.128	222

Table 50. Oat experiment (1962): P uptake by oats (mg/pot).

Treatment	3-4 leaf stage				5-6 leaf stage				before "heading"				after "heading"				Treatment
	$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		
NKMg	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	NKMg
000	11.4	7.8	11.0	8.0	20.4	13.3	20.2	14.8	25.5	15.8	22.6	14.0	26.2	15.1	25.9	17.7	000
001	8.8	6.8	9.3	6.8	21.2	12.8	19.1	14.4	20.3	15.7	21.7	13.3	26.4	17.6	24.1	12.0	001
002	10.7	6.7	10.1	7.4	20.5	13.8	14.3	12.2	20.0	14.1	20.1	16.6	21.9	17.3	24.6	16.4	002
010	9.9	5.9	9.3	3.3	20.4	14.3	19.8	13.9	23.3	16.1	23.2	15.9	27.1	18.6	22.6	15.7	010
011	11.9	6.8	10.5	6.6	19.6	11.7	20.7	13.7	13.1	16.8	22.6	16.9	28.0	19.1	24.3	16.9	011
012	10.0	7.4	9.7	6.4	20.9	12.6	19.8	15.9	20.3	15.0	20.4	15.0	25.0	15.2	22.8	16.8	012
020	10.3	5.9	10.3	7.0	19.4	12.0	18.4	10.8	19.3	15.4	21.5	15.7	25.0	16.8	25.5	19.3	020
021	10.6	9.1	10.1	7.6	20.1	13.3	20.0	15.8	22.6	15.8	21.5	16.7	26.6	20.5	26.1	18.3	021
022	9.9	6.1	10.3	7.8	9.8	12.5	19.9	13.1	22.4	16.2	21.5	14.9	24.3	16.3	26.0	17.7	022
100	14.6	10.5	13.7	10.3	26.6	17.3	27.4	15.8	31.0	22.9	28.9	20.3	31.5	24.8	32.3	21.2	100
101	14.8	8.5	9.9	8.5	26.7	12.2	24.4	16.2	34.1	23.1	31.7	20.3	36.8	23.8	35.8	23.7	101
102	11.7	9.2	9.9	6.7	25.1	14.9	21.9	19.0	19.4	22.2	28.1	21.8	37.1	28.2	31.7	26.6	102
110	10.6	9.6	9.0	7.0	25.5	17.2	23.8	16.1	29.3	21.7	28.8	17.7	33.1	27.8	33.6	25.1	110
111	15.1	10.8	12.2	7.8	27.8	19.0	26.7	19.5	35.3	23.7	29.9	20.8	37.4	27.4	37.9	24.7	111
112	15.4	9.3	10.7	6.9	23.8	12.6	21.5	13.0	27.8	14.9	26.9	18.1	31.4	23.3	24.9	23.4	112
120	14.6	8.0	11.0	9.5	26.8	15.1	14.0	15.0	31.2	17.2	26.4	17.5	36.1	27.9	35.7	26.3	120
121	12.8	9.4	8.3	8.7	22.3	16.8	19.7	16.1	27.7	20.8	23.3	19.6	29.6	25.4	33.0	24.4	121
122	13.6	8.7	11.5	8.5	25.5	14.9	15.7	15.6	29.3	18.3	27.3	21.0	34.3	27.8	31.3	23.9	122
200	12.6	9.6	9.0	7.8	20.4	14.6	20.7	15.1	30.1	22.7	26.3	22.5	38.4	28.6	33.1	25.8	200
201	17.9	10.0	15.4	9.1	26.2	15.8	24.2	15.9	29.6	20.3	28.0	20.1	36.1	23.8	33.3	19.8	201
202	15.3	8.4	12.1	9.2	23.9	16.8	22.1	15.5	27.1	19.7	26.9	16.2	38.7	25.8	35.8	23.4	202
210	15.5	10.9	11.8	7.6	26.6	16.4	21.7	15.2	30.3	22.0	28.7	17.0	41.0	25.3	35.3	19.9	210
211	15.2	7.9	10.8	7.0	24.9	14.8	27.8	17.0	29.3	18.2	27.7	16.1	34.7	21.8	37.4	23.9	211
212	5.5	19.2	13.2	8.2	23.2	16.7	20.3	16.6	33.9	19.9	27.0	23.2	40.6	24.3	36.7	27.2	212
220	22.0	28.3	17.1	9.0	24.7	13.0	22.5	16.0	32.3	24.7	29.7	21.8	32.3	23.6	27.5	24.4	220
221	16.6	7.7	11.1	9.8	21.4	13.1	21.4	15.2	26.9	22.3	31.2	20.2	40.0	23.2	36.5	24.2	221
222	16.4	8.8	10.4	9.5	26.6	17.9	18.9	13.1	37.1	24.1	27.7	20.4	43.7	26.2	32.1	25.1	222

Table 51. Oat experiment (1962): Final soil analysis.

"Available" nutrients (mg/100 g soil-sand mixture)

Treatment	P				K				Mg				Treatment
	$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		$(NH_4)_2SO_4$		$Ca(NO_3)_2$		
NKMg	A	B	A	B	A	B	A	B	A	B	A	B	NKMg
000	.43	.19	.42	.18	3.6	4.9	4.0	5.9	7.0	5.3	7.5	6.0	000
001	.47	.21	.48	.20	3.9	5.1	3.5	5.7	9.0	7.7	9.0	8.9	001
002	.46	.18	.40	.17	3.5	5.0	2.9	4.4	11.3	9.8	11.5	10.5	002
010	.52	.21	.44	.20	3.9	6.7	4.1	6.3	6.9	6.1	7.2	5.9	010
011	.58	.20	.60	.19	3.9	7.1	2.0	6.9	10.0	8.5	9.3	8.4	011
012	.52	.19	.45	.22	4.5	4.7	4.6	5.7	11.4	7.2	11.2	10.1	012
020	.46	.17	.40	.21	5.5	7.5	5.2	7.7	7.1	5.4	8.0	5.6	020
021	.56	.20	.48	.19	7.0	8.1	5.1	8.6	9.0	8.6	9.4	8.5	021
022	.46	.18	.45	.18	6.4	7.2	5.5	8.1	11.3	9.4	10.4	9.7	022
100	.47	.19	.50	.18	2.5	3.4	2.7	3.3	7.7	6.0	7.5	6.1	100
101	.51	.21	.54	.18	2.4	3.3	2.5	3.4	9.1	8.5	10.5	8.3	101
102	.45	.20	.44	.19	2.2	3.0	2.4	3.2	11.9	9.5	11.8	9.3	102
110	.42	.20	.44	.18	2.9	3.5	2.7	4.1	7.0	5.8	7.2	6.2	110
111	.51	.19	.54	.21	3.0	3.3	2.9	3.8	9.6	8.5	10.5	7.5	111
112	.43	.20	.56	.18	3.1	4.1	5.2	4.0	11.4	9.7	11.2	10.3	112
120	.48	.20	.47	.17	2.9	4.2	3.6	4.8	6.8	5.0	7.5	6.3	120
121	.48	.19	.44	.18	3.8	4.0	3.5	4.7	9.4	8.5	10.0	8.3	121
122	.47	.18	.47	.18	2.9	3.5	4.1	4.9	11.8	8.7	11.9	10.4	122
200	.43	.22	.40	.17	2.6	3.1	2.7	3.2	6.9	5.4	7.0	5.5	200
201	.49	.19	.58	.17	2.7	3.1	2.5	3.2	10.1	7.1	9.6	6.2	201
202	.38	.22	.40	.17	2.8	3.6	2.7	3.2	11.1	9.2	11.2	8.1	202
210	.51	.20	.51	.17	2.6	3.7	3.1	5.2	7.4	6.1	7.0	5.9	210
211	.43	.20	.50	.19	2.8	4.3	3.1	4.3	9.5	7.8	11.4	7.0	211
212	.44	.20	.45	.19	2.8	3.7	2.7	3.5	12.3	9.2	12.3	8.6	212
220	.49	.19	.50	.18	3.4	4.5	3.5	4.6	7.5	5.6	7.6	5.5	220
221	.42	.19	.48	.17	3.3	4.5	3.6	4.0	9.4	8.4	10.1	8.1	221
222	.37	.19	.43	.18	3.4	3.5	3.8	4.5	11.4	8.9	11.1	9.7	222

Table 51 (contd.). Oat experiment (1962): Final soil analysis.

Treatment NKMg	Loss of "available" Mg (mg/pot) $(NH_4)_2SO_4$ A	$(NH_4)_2SO_4$ B	$Ca(NO_3)_2$ A	$Ca(NO_3)_2$ B	pH $(NH_4)_2SO_4$ A	$(NH_4)_2SO_4$ B	$Ca(NO_3)_2$ A	$Ca(NO_3)_2$ B	Treatment NKMg
000	233	36	208	-1	7.6	5.9	7.5	6.0	000
001	321	101	321	41	7.3	6.1	7.3	6.0	001
002	395	184	383	150	7.3	5.9	7.3	5.9	002
010	238	-6	224	4	7.3	6.0	7.4	6.0	010
011	271	61	308	67	7.4	6.1	7.5	6.0	011
012	390	318	401	168	7.4	6.0	7.4	5.9	012
020	229	29	181	16	7.3	6.1	7.2	6.0	020
021	322	55	301	61	7.2	6.1	7.3	6.2	021
022	395	205	439	190	7.4	5.9	7.3	6.0	022
100	186	-17	191	-17	7.3	5.8	7.3	5.9	100
101	307	45	232	62	7.4	5.7	7.5	5.8	101
102	351	183	360	199	7.3	5.8	7.3	5.9	102
110	225	-6	215	-21	7.3	5.8	7.3	5.9	110
111	280	45	233	98	7.2	5.8	7.3	6.0	111
112	379	176	392	148	7.3	5.7	7.3	5.9	112
120	234	34	196	-29	7.3	5.7	7.5	5.9	120
121	292	46	259	59	7.2	5.7	7.4	5.9	121
122	408	224	352	142	7.2	5.8	7.4	6.0	122
200	214	5	211	1	7.0	5.5	7.4	6.0	200
201	243	113	271	162	7.2	5.6	7.5	6.0	201
202	375	188	378	249	7.5	5.5	7.6	5.9	202
210	188	-28	213	-7	7.3	5.5	7.5	5.8	210
211	270	79	178	141	7.2	5.4	7.3	6.0	211
212	319	196	326	222	7.1	5.5	7.5	6.0	212
220	189	0	186	6	7.1	5.7	7.2	6.1	220
221	281	45	245	63	7.2	5.5	7.4	6.0	221
222	365	206	386	171	7.2	5.5	7.3	6.0	222

APPENDIX IV. Results of the Oat Experiment (1963).

Table 52. Layout of the oat experiment (1963).

	Treatment				
	CaNMg	CaNMg	CaNMg	CaNMg	CaNMg
	201	321	121	221	200
	021	210	111	220	101
Replicate 1	010	211	320	100	001
	311	120	301	110	000
	300	020	310	011	—
	200	101	121	210	120
	310	010	201	301	020
Replicate 2	220	100	021	001	111
	320	211	011	300	221
	—	000	110	311	321

Table 53. Weekly weather data for the oat experiment (1963). The observations were made at Bush House, 1½ miles west of the experimental site.

Date (1963)	Precipitation (in.)			Temperature (°F)		Sunshine (hours)
	Rainfall	Added water	Total	Max.	Min.	
26– 1 Apr.	0.53	0.00	0.53	44.9	34.1	21.5
2– 8 "	0.84	0.67	1.51	44.0	34.6	23.9
9–15 "	0.99	0.00	0.99	46.0	34.1	37.3
16–22 "	0.53	0.00	0.53	51.7	38.7	17.5
23–29 "	0.16	0.00	0.16	57.9	42.1	30.0
30– 6 May	0.53	0.00	0.53	50.6	37.0	48.8
7–13 "	0.53	0.27	0.80	54.4	41.5	23.9
14–20 "	0.79	0.00	0.79	53.6	40.6	30.0
21–27 "	0.39	0.27	0.66	55.4	39.7	35.2
28– 3 June	0.00	1.61	1.61	61.4	43.0	75.0
4–10 "	0.46	0.67	1.13	60.9	46.0	33.2

Table 54. Oat experiment (1963): Yield (g/pot).

Treatment CaNMg	Fresh yield 1†	Fresh yield 2	Dry matter yield 1	Dry matter yield 2	% Dry matter 1	% Dry matter 2
000	11.0	9.7	2.12	1.83	19.3	18.9
001	11.6	11.4	2.18	2.10	18.7	18.4
010	14.0	15.5	2.67	2.83	19.1	18.3
011	22.4	22.7	3.94	4.00	17.6	17.6
020	13.8	15.7	2.49	2.82	18.1	18.0
021	21.1	21.2	3.68	3.68	17.4	17.3
100	16.1	14.6	3.22	3.00	20.1	20.5
101	15.7	15.5	3.09	3.25	19.7	21.0
110	30.9	28.3	5.64	5.40	18.3	19.1
111	35.0	32.7	6.43	5.91	18.4	18.1
120	33.5	29.8	6.13	5.51	18.3	18.5
121	30.3	25.6	5.26	4.87	17.3	19.0
200	25.6	25.8	5.02	5.39	19.6	20.9
201	23.2	27.5	4.82	5.24	20.7	19.1
210	38.7	39.1	6.97	7.05	18.0	18.0
211	41.9	40.7	7.48	7.23	17.8	17.7
220	38.5	32.6	6.20	5.40	16.1	16.6
221	37.7	44.7	6.30	7.40	16.7	16.5
300	30.8	32.3	6.02	6.03	19.6	18.6
301	36.9	35.2	7.10	6.78	19.2	19.3
310	37.7	36.6	6.33	6.31	16.8	17.2
311	42.7	41.4	7.51	7.14	17.6	17.3
320	42.7	37.2	6.95	6.04	16.3	16.2
321	47.5	46.6	7.45	7.32	15.7	15.7

† These figures denote the replicate.

Table 55. Oat experiment (1963): Mineral content of oats (%).

Treatment	K		Na		Ca		Mg		P		N		Treatment
CaNMg	1†	2	1	2	1	2	1	2	1	2	1	2	CaNMg
000	3.03	3.12	.111	.117	.32	.34	.078	.101	.179	.192	1.68	1.88	000
001	3.02	3.10	.039	.030	.21	.20	.368	.351	.317	.286	1.60	1.60	001
010	3.53	3.53	.054	.053	.28	.25	.061	.064	.153	.165	3.10	3.20	010
011	3.65	3.57	.025	.026	.13	.14	.234	.264	.190	.194	3.22	3.12	011
020	3.57	3.57	.067	.067	.48	.47	.068	.079	.164	.147	3.50	3.40	020
021	3.71	3.69	.055	.036	.52	.41	.257	.253	.185	.170	3.48	3.40	021
100	2.64	2.55	.034	.029	.61	.61	.087	.088	.340	.329	1.24	1.24	100
101	2.93	2.57	.036	.029	.65	.62	.159	.138	.340	.284	1.38	1.24	101
110	3.02	3.03	.043	.043	.60	.65	.063	.081	.173	.168	3.12	3.04	110
111	3.11	3.07	.049	.053	.60	.58	.133	.145	.165	.167	2.96	2.94	111
120	2.90	3.00	.101	.104	.70	.70	.089	.097	.148	.147	3.08	3.08	120
121	3.24	2.99	.196	.091	.77	.63	.195	.170	.157	.144	3.40	2.76	121
200	2.77	2.43	.036	.029	.85	.60	.086	.080	.243	.184	1.88	1.70	200
201	2.68	2.88	.037	.034	.51	.53	.128	.133	.150	.225	2.08	1.78	201
210	3.02	3.02	.090	.062	.61	.61	.090	.093	.187	.190	3.08	3.16	210
211	3.02	3.05	.090	.081	.63	.57	.146	.165	.178	.187	3.10	3.12	211
220	3.71	3.67	.148	.138	.87	.77	.099	.102	.222	.207	3.70	3.76	220
221	3.53	3.30	.188	.178	.73	.70	.199	.205	.187	.207	3.64	3.28	221
300	2.82	2.94	.030	.029	.65	.68	.085	.092	.227	.284	2.12	2.08	300
301	2.73	2.53	.026	.039	.65	.61	.142	.139	.280	.209	1.88	1.92	301
310	3.32	3.20	.089	.087	.73	.73	.086	.089	.236	.200	3.60	3.42	310
311	3.18	3.29	.096	.111	.62	.69	.168	.182	.214	.207	3.24	3.32	311
320	3.30	3.95	.153	.125	.83	.93	.080	.095	.227	.253	3.98	4.00	320
321	3.40	3.55	.229	.198	.82	.91	.179	.189	.252	.240	3.92	3.76	321

† These figures denote the replicate.

Table 56. Oat experiment (1963): Mineral uptake by oats (mg/pot).

Treatment	K		Na		Ca		Mg		P		N		Treatment
CaNMg	1†	2	1	2	1	2	1	2	1	2	1	2	CaNMg
000	64	57	2.4	2.1	6.8	6.2	1.7	1.8	3.8	3.5	36	34	000
001	66	65	0.7	0.6	4.6	4.2	8.0	7.4	7.4	6.0	35	34	001
010	94	100	1.4	1.5	7.5	7.1	1.6	1.8	4.1	4.7	83	91	010
011	144	143	1.0	1.0	5.1	5.6	9.2	10.6	7.5	7.8	127	125	011
020	89	101	1.7	1.9	12.0	13.3	1.7	2.2	4.1	4.1	87	96	020
021	137	136	2.0	1.3	19.1	15.1	9.5	9.3	6.8	6.3	128	125	021
100	85	77	1.1	0.9	19.6	18.3	2.8	2.6	10.9	9.9	40	37	100
101	91	84	1.1	0.9	20.1	20.1	4.9	4.5	10.5	9.2	43	40	101
110	170	164	2.4	2.3	33.8	35.1	3.6	4.4	9.8	9.1	176	164	110
111	200	181	3.2	3.1	38.6	34.3	8.6	8.6	10.6	9.9	190	174	111
120	178	165	6.2	5.7	42.9	38.6	5.5	5.3	9.1	8.1	189	170	120
121	170	146	10.3	4.4	40.5	30.7	10.3	8.3	8.3	7.0	179	134	121
200	139	131	1.8	1.6	42.7	32.3	4.3	4.3	12.2	9.9	94	92	200
201	129	151	1.8	1.8	24.6	27.8	6.2	7.0	7.2	11.8	100	93	201
210	210	213	6.3	4.4	42.5	43.0	6.3	6.6	13.0	13.4	215	223	210
211	226	221	6.7	5.9	47.1	41.2	10.9	11.9	13.3	13.5	232	226	211
220	230	198	9.2	7.5	53.9	41.6	6.1	5.5	13.8	11.2	229	203	220
221	222	244	11.8	13.2	50.0	51.8	12.5	15.2	11.8	15.3	229	243	221
300	170	177	1.8	1.7	39.1	41.0	5.1	5.1	13.7	17.1	128	125	300
301	194	172	1.8	2.6	46.1	41.4	10.1	9.4	19.9	14.2	133	130	301
310	210	202	5.6	5.5	46.2	46.1	5.4	5.6	14.9	12.6	228	216	310
311	239	235	7.2	7.9	46.6	49.5	12.6	13.0	16.1	14.8	243	237	311
320	229	239	10.6	7.5	57.5	56.2	5.1	5.4	15.8	15.3	277	242	320
321	253	260	17.1	14.5	61.1	66.6	13.3	13.8	18.8	17.6	292	275	321

† These figures denote the replicate.

Table 57. Oat experiment (1963): Mg deficiency symptoms.

Treatment Ca/Mg	Sympton score 29 May 1†	29 May 2	5 June 1	5 June 2	Increase in the sympton score 1	2
000	10	10	10	10	0	0
001	10	10	10	10	0	0
010	8	7	7	7	-1	0
011	10	10	10	10	0	0
020	7	8	7	7	0	-1
021	10	10	10	10	0	0
100	10	10	10	10	0	0
101	10	10	10	10	0	0
110	6	6	7	7	1	1
111	10	10	10	10	0	0
120	10	10	10	10	0	0
121	10	10	10	10	0	0
200	7	8	9	9	2	1
201	10	10	10	10	0	0
210	7	7	9	9	2	2
211	10	10	10	10	0	0
220	8	8	9	9	1	1
221	10	10	10	10	0	0
300	7	8	8	9	1	1
301	10	10	10	10	0	0
310	6	6	7	7	1	1
311	10	10	10	10	0	0
320	6	6	7	7	1	1
321	10	10	10	10	0	0

† These figures denote the replicate.

Table 58. Oat experiment (1963): Final soil analysis.

Treatment	pH		"Available" nutrients (mg/100 g soil) P		K		Mg		Loss of "available" Mg (mg/pot)		ppm N in oven-dry soil NH_4-N		NO_3-N		Treatment
CaNMg	1†	2	1	2	1	2	1	2	1	2	1	2	1	2	CaNMg
000	4.9	5.0	.35	.33	6.1	6.5	1.2	1.7	19	-7	2.0	3.1	1.0	1.4	000
001	4.6	4.7	.36	.35	6.0	5.6	5.0	4.7	72	71	1.4	1.8	1.8	1.3	001
010	4.4	4.6	.35	.37	6.4	5.8	1.8	1.3	-12	13	25.4	23.5	3.1	1.9	010
011	4.4	4.5	.43	.33	5.3	5.4	4.6	5.4	74	31	18.1	23.3	0.5	1.6	011
020	4.6	4.6	.34	.40	5.7	5.7	0.9	1.9	34	-17	8.5	2.7	22.2	25.1	020
021	4.6	4.6	.36	.36	5.4	5.2	5.1	4.3	48	89	2.6	2.4	18.2	15.2	021
100	5.9	6.0	.31	.29	5.8	6.1	1.2	1.5	18	2	1.5	1.9	1.9	2.4	100
101	5.8	5.8	.34	.31	5.6	5.8	5.0	5.1	57	52	1.8	1.9	1.4	1.6	101
110	5.6	5.8	.31	.30	5.3	5.1	0.9	1.3	32	11	4.9	9.5	3.4	2.0	110
111	5.7	5.6	.33	.31	4.5	4.7	5.0	5.4	53	33	5.4	5.0	2.2	1.8	111
120	6.0	6.1	.29	.29	4.9	5.5	1.3	1.1	10	21	2.1	2.3	4.3	9.7	120
121	5.9	5.9	.32	.31	5.8	5.7	5.0	4.0	52	105	2.2	2.0	5.6	4.7	121
200	6.7	6.8	.30	.28	4.7	5.1	1.6	0.5	-4	52	6.6	3.2	1.6	2.0	200
201	6.6	6.4	.35	.29	6.3	4.9	5.1	5.1	51	50	2.7	3.2	3.7	2.0	201
210	6.4	6.6	.28	.25	4.2	4.2	1.4	0.7	4	39	3.1	5.6	4.8	2.9	210
211	6.4	6.6	.31	.25	4.2	3.9	5.0	5.1	51	45	5.1	5.7	2.8	3.9	211
220	6.8	6.6	.24	.28	4.0	4.9	1.3	0.8	9	36	3.1	4.2	7.5	18.1	220
221	6.6	6.8	.29	.26	4.9	3.6	4.7	4.4	65	78	2.8	3.8	8.3	4.8	221
300	7.2	7.0	.31	.31	3.8	3.7	0.4	1.3	56	10	5.2	4.9	1.4	3.4	300
301	7.4	7.1	.29	.33	3.6	4.2	4.1	3.8	98	115	3.9	4.2	3.4	2.8	301
310	7.2	6.9	.31	.31	3.7	4.0	0.6	0.4	46	55	8.2	10.0	6.1	5.5	310
311	6.8	7.0	.31	.31	3.9	3.9	4.1	4.1	95	95	10.7	10.8	4.2	5.6	311
320	7.4	7.2	.28	.31	4.0	3.5	1.0	1.3	26	10	5.2	6.5	7.5	19.2	320
321	7.4	7.2	.33	.30	3.9	3.6	3.6	4.1	121	94	5.0	21.0	6.0	9.6	321

† These figures denote the replicate.